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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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Articles submitted for publication to the JOURNAL OF SEDIMENTARY PETROLOGY should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 3, PP. 91–103, FIG. 1, DECEMBER, 1937

THE DIAMOND HEAD BLACK ASH

CHESTER K. WENTWORTH
Board of Water Supply, Honolulu, Hawaii

ABSTRACT

Black ash, or cinders from explosive volcanic eruptions, form conspicuous surficial deposits in the Tantalus, Makiki, and other parts of Honolulu. The fine-grained black sand deposits southeast of Diamond Head and along the Black Point coast have long been considered to be true black ash of explosive origin. Recently the Diamond Head material has been described as the product of wave action on coastal rocks, drifted inland by the wind to form dunes, hence a sand rather than a true ash formed by explosion. In order to determine which of these views is correct, the writer has repeated and extended earlier field and microscopic examination of the material in question. The result is a complete substantiation of the original view. About 98 per cent of the fragments are glass, in vesicular, pulled, droplet forms, with delicate, unbroken points, and with no sign of abrasion, Structure, bedding, and distribution, as well as the composition, all strongly indicate formation by volcanic explosion, with but a minor part indicating some contemporaneous movement by the wind. Final proof of the volcanic interpretation is afforded by a one-inch layer of volcanic pisolites, or accretionary lapilli, which have been traced in the formation some 500 feet along the Black Point coast. These pisolites are tiny mud balls about a half millimeter in diameter which were formed around raindrops which fell through the dust-laden air during a brief shower which accompanied the eruption. Such pisolites are well known at Kilauea, and their formation has been observed by many geologists. The black ash beds lie on a reef conglomerate containing rounded boulders derived from the earlier Black Point lava flow and hence are the product of a second Black Point eruption. The explosive phase was probably induced when the molten lava entered the sea, the explosive eruption being of the littoral type, like that which formed Puu Hou near Kalae, Hawaii, in 1868. It evidently took place when the sea stood no higher than at present and was much the most recent volcanic event in the Diamond Head area.

Nearly all observers of the geology of the Honolulu region on Oahu have noted the "black sand" formation which crops out in a limited area on the southeast slope of Diamond Head and along parts of the nearby Black Point coast. There are several pyroclastic formations in the Honolulu area consisting of glassy, more or less vesicular particles, ranging downward from sizes of a quarter inch or less. The most important is the product of explosive eruptions from the Tantalus-Sugarloaf vents, which lies at or just below the present surface in the Makiki and downtown district, generally. The "black sand" of the Diamond Head-Black Point area, though much finer than most of the other formations, shows similar features and has generally been considered to be the immediate product of an explosive eruption, though the source vent has not been identified.[1]

Recently, in his report on the geology of Oahu, Stearns has stated that this formation is not of pyroclastic origin but is composed of grains formed by the action of waves on the nearby coast and subsequently drifted inland by the wind. If this

[1] Hitchcock, C. H., Geology of Oahu: *Geol. Soc. America, Bull.*, vol. 2, pp. 45, 52, 56, 1900.
Geology of Diamond Head: *Geol. Soc. America, Bull.*, vol. 17, p. 480, 1906. Hawaii and its volcanoes, p. 35, Honolulu, 1911.
Wentworth, C. K., Pyroclastic geology of Oahu: *B. P. Bishop Mus., Bull.* 30, pp. 45, 99, 1926.

view is correct, the problem of finding the source vent is readily dismissed. Moreover, in this area, there are extensive dunes of calcareous sand formed in this manner, whose presence gives a certain plausibility to the eolian interpretation. Stearns' view is expressed in the following words,

> These dunes exhibit cross-bedding typical of wind deposition. The grains are uniformly small and well sorted, although concretionary nodules occur here and there among them. This is unquestionably the material mistaken for black ash by early writers. The grains consist of olivine, glass, basalt, and limestone. The limestone grains make up from 5 to 10 per cent of the mass and appear to have furnished the cement for the partial lithification of the dunes. The grains are rounded and are typical sand such as might be blown from a beach formed by waves beating against a basalt and tuff coast.[2]

However, the characteristics of this formation, when examined in detail, are not in accord with this interpretation and indicate that the accepted view of earlier writers is not so easily set aside. If the eolian hypothesis is correct, there is no occasion to search for a vent from which pyroclastic material was ejected; on the other hand, if the "black sand" formation is truly the product of an explosive eruption, it represents an episode in the history of the Black Point district which should not be ignored. In order that these sharply-contrasted views may be considered, a description of the formation is presented below, together with some statements on the origin of sand in general, and in Hawaii in particular.

[2] Stearns, H. T., Geology and groundwater resources of the Island of Oahu, Hawaii, Territory of Hawaii: *Division of Hydrography, Bull.* 1, p. 142, 1935.

AREAL AND STRUCTURAL RELATIONS

The black ash formation is found only in a limited area on the southeast[3] lower slope of Diamond Head, and near the upper margin of a short portion of the abraded coastal zone of Black Point. The principal inland exposures lie along the Diamond Head belt road, southwest and northeast of the junction with Kahala Avenue, where the formation is seen to be underlain and overlain by earlier and later parts of the Diamond Head talus breccia, respectively. Other cinder and ash beds are encountered occasionally in pits and drill holes farther inland, but for the most part they appear not to be correlative with this formation.

On the Black Point coast the ash overlies a reef and beach conglomerate which contains rounded boulders of Black Point basalt and is, therefore, distinctly younger than the Black Point basalt. In an earlier report, the present writer, in discussing the possible affinities of the back ash, and after describing the Kaimuki and Black Point basalts, stated that

> It seems probable that it (the black ash) is contemporaneous with the basalts and either issued from the same vents as an auxiliary phase of the eruption, or as seems more likely, came from the small crater Mauumae north of Waialae Road, ...

In this statement he was guilty of

[3] On p. 138 of his report Stearns locates this sand on the "southwest" slope of Diamond Head, but this is believed to be an inadvertence, since the description indicates clearly that he refers to the same outcrop.

overlooking the abovementioned relationship of ash above the basalt-bearing reef conglomerate, though this was observed and recorded in an explicit sequence of events enumerated in field notes dated October 2, 1923.

STRATIFICATION

Three types of bedding are observed in the black ash. The larger part of the formation shows a characteristic mantle bedding of the type developed in pyroclastic formations deposited from the air. In addition to this dominant, laminated or zoned structure, there are small masses, mostly lying above the mantle-bedded parts, which are massive and practically devoid of zoning, and also a few places where steeply-dipping, dune foreset bedding is developed.

Mantle bedding has been described in detail elsewhere.[4] The mantle bedding of the black ash consists of a uniform, delicate zoning in long, sweeping plane or gently curved configuration. It is hardly correct to speak of bedding planes, since much of the zoning consists of delicate but laterally continuous and uniform zones of varying coarseness of particles. Only rarely are well-marked partings of distinctly finer material found. The structure makes it clear, from the wide extent of given thin zones, and their parallelism to the surface on which they were mantled, that the material was deposited by settling from the air, rather than transgressively, by wind, as in the formation of dunes, or less concentrated drifted sand. As observed elsewhere, the variations in coarseness seem to be due to successive invasion and non-invasion of coarser grains due to pulsations in the violence of the explosive expulsion, while the finer material fell more continuously from the higher air over a given site. The zonation visible from a distance of a few feet has a spacing of one to several inches, but closer scrutiny shows in many places a precise, though faint alternation of coarseness with spacing of not over one or two millimeters. In most places the zones are of uniform thickness for many feet, but occasionally, where the formation is mantled over an irregular surface there is a marked change of thickness of a series of zones, in what may be called sheaf-bedding. This somewhat resembles certain eolian bedding structures but there is lacking the overlapping, and variable type of cross-bedding common to wind-deposited beds.

In a number of places, above the regular, finely zoned beds, are small amounts of massive black ash, in which no clear bedding appears and which are thought to be due possibly to contemporaneous slumping at the time of deposition. Such non-zoned and slightly coarser beds are prominent in the exposures along the coast. In the latter place, owing to proximity to the now-supposed focus of eruption, the lack of clear zoning is thought to be due to imperfect sorting under the disturbed conditions close to site of explosion.

[4] Wentworth, C. K., Op. cit., pp. 25–27, 1926. Pyroclastic formations of the Island of Hawaii, Unpublished manuscript, pp. 47–50, 1932.

Conspicuously in one exposure on the Diamond Head slope, and to a lesser degree elsewhere, cross-bedded ash, with structure of the dune foreset type is found. At this point the laminae, more sharply separated than common in the mantle-bedded material, dip 30°, S 55° E. This material is quite likely of eolian placement. However, an examination of the whole area shows that material with such eolian bedding constitutes a very small fraction of the whole formation, probably not over 2 or 3 per cent, and is wholly absent from most exposures.

CEMENTATION

Very little of the formation is sufficiently cemented to form a good hand specimen. Because of its porous texture and irregularity of grain shapes it stands in vertical banks a few feet high where exposed, but is subject to continuous undermining and wastage by wind or other disturbance. Where masses of it fall a few feet, occasional blocks a few inches to a foot across survive but can rarely be handled without further breakage. Most of the outcrops display certain zones, or irregular pipes or plant-stem moulds which have been secondarily filled or cemented by calcium carbonate. The calcareous parts of the formation in places consist of nearly solid calcium carbonate, with little or none of the black ash in the mass, and in others of a firm cementing of the ash, with preservation of the original structure.

Stearns suggested that the calcareous grains of the ash itself may have furnished the material for such cementing, but owing to the slight thickness of the formation, the presence of heavy calcareous crusts, as much above it as below it, and the very general deposition of secondary calcium carbonate in the Diamond Head tuff, in the talus breccia derived from the tuff, and in association with the calcareous dunes of the district, it is more reasonable to suppose that most of the calcium carbonate came from the tuff and from the calcareous sand of the dunes. It has been common to point to reef rock and other calcareous fragments of the tuff as sources of such vein material, but it should be emphasized that both tuff and basalt are rocks fairly high in lime and that one of the elementary processes of weathering is the production of calcium carbonate by carbonation of minerals which contain the lime or calcium oxide as a part of their complex molecular structure. This process, with the transportation of the calcium carbonate in solution in stream waters to the sea, is responsible for most of the calcium carbonate in the sea, from which corals and other organisms derive the material for the complex series of reef and beach rocks.

MECHANICAL COMPOSITION

The grain size of the black ash ranges from 1 mm. down to less than 1/50 mm. The distribution of grain sizes is shown in the following table of mechanical analyses. In specimens 486, 492-A, and 495 there is considerable variation in the position of the

Mechanical analyses of black point ash

Sieve Openings (mm.)	Specimen Numbers				
	486 (per cent)	492-A (per cent)	495 (per cent)	492-C (per cent)	492-D (per cent)
0.707 –1.00	tr.	1.0	—	—	—
0.500 –0.707	0.3	4.4	0.9	0.5	0.4
0.354 –0.500	3.3	10.2	51.1	51.2	31.0
0.250 –0.354	11.8	17.7	29.4	30.4	52.3
0.177 –0.250	17.1	27.1	6.8	8.1	7.6
0.125 –0.177	15.6	25.5	5.3	5.8	4.7
0.088 –0.125	19.7	12.1	4.4	3.2	3.2
0.0625–0.088	17.0	1.5	1.6	0.7	0.8
under 0.0625	15.2	0.5	0.5	0.1	—

Specimen 486, From bank 200 feet up Diamond Head slope from belt road 1,700 feet northeast of intersection with Kahala Road.

Specimen 492-A, C, and D, From bank 30 feet up slope from road, 700 feet west of intersection with Kahala Road. Specimens C and D were collected by scraping grains from an individual zone 1 to 2 mm. thick on the surface of a block.

Specimen 495, From outcrop on southwest shore of Black Point near dike.

maximum grade. Inspection under the microscope shows that this is due to the varying proportions of coarser or finer laminae included in the analysis. Each of the samples analysed consisted of a small slab about 1 inch thick, and showed several recognizable laminae. Sample 495 was of the massive type and shows a far more marked concentration in one of the coarser grades with the tailing down in the finer grades which has been thought to be characteristic of pyroclastic detritus.

On working over various samples under the microscope it was seen that some of the coarser, blacker layers consist almost wholly of grains one-half to 1 mm. in diameter, whereas other, grayer, more powdery layers consist mostly of one-thirty-second mm. grains. Layers of all intermediate degrees of fineness are common. Analyses of specimens 492-C and 492-D show results of an attempt to isolate certain layers by scraping off the surfaces of blocks broken along the stratification. The analyses show a marked concentration of grains in certain grade sizes, despite the difficulty of excluding parts of adjacent thin zones. Both show the tailing off of finer grades already mentioned, and 492-C is remarkably similar in composition to 495 although collected in a different manner at another locality. Most of the grains are compact and nearly equidimensional, but a few elongate glass threads are seen in most samples and some are striking bits of Pele's hair as much as 5 mm. in length.

MINERAL COMPOSITION

The mineral composition is indicated by the statement that the formation, assuming the slight induration which is found locally, is a striking example of vitric tuff. All other constituents together probably do not anywhere exceed 3 per cent of the whole, the bulk of the mass consisting of basaltic glass pellets and

shards of varying degrees of vesicularity. Each screened separate of the several analyses given above was examined under the binocular microscope and density and magnetic separations made on certain fractions.

In the grades above one-half mm. in one of the samples (486), a count of over 500 grains showed more than 98 per cent glass pellets, with less than 2 per cent of calcareous particles, probably from reef rock near the shore, involved in the explosion. Two grains tentatively identified as tuff were noted. Sample 495 contains much less calcareous material, estimated as under one-tenth of one per cent throughout, than the other samples. The glass pellets show a characteristic range from dark, coarsely vesicular, but fairly clear glass, to light, golden yellow, minutely pumiceous, or almost reticulitic glass. Both types are chunky masses, of nearly equal dimensions in various directions. The surfaces of the darker pellets show some smoothness due to retraction of the glass while liquid, but also many sharp and jagged, broken edges. The yellow pellets show broken pumiceous textures, delicate points, fragile exposed nets and the like. There is no evident rounding by abrasion. A few elongate sections of fluted, yellow, pumiceous glass threads are found.

In grades from one-half to one-fourth mm., there appears to be a slight increase of calcareous debris, reading 4 per cent in one fraction where grains were counted. There is also an increase of the darker and presumably denser, more coarsely vesicular glass. Fewer of the glass pellets are complete and there are more jagged, broken bits. More elongate threads and a few pieces of Pele's hair up to 4 or 5 mm. in length. are found here. A few olivine grains, more or less freed from surrounding glass, appear in these grades. In the 0.25 to 0.354 mm. grade of sample 486, a separation made with bromoform at density of 2.81, showed 11 per cent olivine and olivine with glass in the heavy fraction, and 89 per cent, chiefly glass, in the light.

Below one-fourth mm. the grades show an increase of broken glass shards, and an increase of partly palagonitized bits of pumiceous glass. The proportion of calcareous debris remains about the same. The 0.88 to 0.125 mm. grade of Sample 495, by bromoform separation contains 4.5 per cent of olivine and olivine-glass grains in the heavy fraction. A small percentage of freed magnetite grains is concentrated in the finer grades, as separated by the magnet and estimated at 3 per cent to 10 per cent in the 0.0625 to 0.088 mm. grades of various samples.

Despite the examination of over a dozen samples from all parts of the formation, and upward of 50 fractions, with the counting of some 2,000 grains under the binocular microscope, not a single grain of basalt, as reported by Stearns, was found. In addition a search was made on the surface of indurated blocks under the binocular microscope and in thin sections under the petrographic microscope with the same negative result.

THE SHAPES OF GRAINS

In the preceding paragraphs the shapes of the grains of basaltic glass and pumice have been described. All these shapes are those commonly produced by volcanic explosion. No grains rounded by abrasion were seen, though many of the grains have an equidimensional form due to retraction of the glass by surface tension into pellets. The calcareous particles are mostly somewhat rounded by solution or crumbling; but show no clear evidence of abrasion. The shapes of the glass particles and of the Pele's hair not only show no evidence of abrasion but are such as to exclude effectually the view that the material was produced by attrition on a beach and placed in its present position by eolian action.

The foregoing description of the mechanical and petrographic features of the Black Point black ash is quite sufficient to establish the explosive origin and emplacement of the formation if no further evidence were available. However, more direct testimony is afforded by a single layer of light-gray ash, more firmly indurated than most, which can be traced for about 500 feet, 1 to 3 feet above the base, along the Black Point shore. So far as known, this layer, with a nearly uniform thickness of slightly over one inch, has escaped the attention of all previous observers. Close examination, even with the naked eye, shows it to be a cemented layer of tiny pisolites, or accretionary lapilli,[5] mostly one-half mm. to 2 mm. in diameter. These are well known at Kilauea and have been formed in historic eruptions by the falling of water droplets, or of larger particles through moist, dust-laden air.[6] They can only mean that the black ash is a true explosion product, since both their structure and their occurrence in a uniform layer of fairly wide extent are indicative of deposition by settling through the air, without controlling wind action.[7]

THE PROCESS OF SAND FORMATION

Differences of opinion as to the origin of the Black Point "sand" suggest not only imperfect observation on the character of that formation but also some misconceptions as to the origin of sand, the world over, and in Hawaii. Like some other common geologic processes, that by which sand is formed is not yet generally well understood, in a critical sense, and the following discussion is a statement of the writer's views, with such evidence as can be conveniently adduced in a brief text.

Sand is defined commonly as an aggregation of somewhat sorted, somewhat abraded, rock or mineral particles having sizes mostly between one-sixteenth and 2 mm. The sorting may be very little, and the abrading

[5] Wentworth, C. K., and Williams, H., The classification and terminology of the pyroclastic rocks: *Nat. Res. Council, Bull.* 89, pp. 35, 37, 45, 1932.

[6] Perret, F. A., Some Kilauean ejectamenta: *Am. Jour. Sci.*, vol. 35, p. 612, 1913. Stearns, H. T., The explosive phase of Kilauea volcano, Hawaii, in 1924: *Bulletin Volcanologique*, Nos. 5 and 6, 3.c et 4.c Trimestre, p. 10, 1925.

[7] Larger dust balls, with a solid nucleus, are probably formed by rolling, snowball fashion on the surface, but such an explanation obviously does not fit this case.

inconspicuous, such as almost inevitably accompanies the segregation of such material in nature. Crushed rock, such as mill tailings, although of appropriate sizes, would hardly be called sand until it had been so shaped or dynamically sorted by handling in a stream or by waves, as to assume some of the character of a natural formation. Sand grades upward into fine gravel and downward to silt sizes, and many sands contain small admixtures of these coarser or finer adjacent grades. However, it has been suggested that the gradation of sizes of natural aggregations of rock and mineral particles is not a uniform one and that well-marked, fairly homogeneous formations of particles in the sand size are much more abundant than are those of immediately coarser or finer particles.[8]

Sand can be formed, and is formed, of particles of any rock or mineral available in sufficient quantity, and of sufficient mechanical and chemical stability and uniformity of stability to react fairly uniformly to the wind, or stream, lake or ocean water, so as to acquire the sorting and shaping inherent in the definition of sand. Likewise, the eolian or aqueous agent must exhibit a sufficient continuity and control of attack to work effectively toward a more or less precise sorting and shaping of the material. Neither landslides, torrential floods, nor so-called tidal waves produce or segregate sand formations. Attention in this discussion is drawn to the nature and availability of the material for the formation of sand grains. If this material consists of some very soft grains and other very hard grains, the result is an imperfect or an immature sand, if indeed the name is merited. In those places where the selective process can go on long enough, there may be formed a mature sand composed of the harder material to the nearly complete exclusion of the softer. Long periods of time, uniformity of conditions, extensive beaches and long rivers are the favorable factors for producing mature sands.

Even these may fail in the production of well-characterized sands if durable material is not available. Availability involves not only presence of the material but also ability of the sorting or other agent to detach or lay hold of the particles and to reduce them to the requisite sizes. With the common process of wave action conspicuous on many coasts, it has been commonly believed that where hard rocks are being carved and removed so as to form benches and cliffs, there also was much sand produced by attrition and battering of wave-driven rocks. However, for many years it has been suspected by some geologists that except as rocks are already prepared by certain types of weathering or by their mineral texture to crumble into sand-sized grains. the battering of rock on rock produces either larger flakes or finer particles much smaller than sand grains, but very little sand-sized material.

[8] Wentworth, C. K., Fundamental limits to the sizes of clastic grains: *Science*, vol. 77, pp. 633, 634, 1933.

This is suggested by the findings of Daubrée, who subjected mineral fragments to abrasion in water in a rotating drum, the resulting products being chiefly clay and dissolved salts in the water.[9] The present writer reached the same conclusion, as did Marshall,[10] both also working on the laboratory shaping of pebbles in a rotating mill. As a result of studies such as these and various discussions in the literature, together with persistent observation of cobble- and boulder-forming processes and abrasive processes in the field, the present writer is convinced that the direct production of sand-sized particles by battering, grinding or abrasive action on hard rocks not incipiently divided into units of favorable size through the mineral texture or some partial physical or chemical weathering, is a very limited and comparatively unimportant process. Some of the best-rounded sands of the world are known to represent more than one cycle of transport, sorting and rounding, and hence the immediate source of the grains lies in some parent sandstone, from which they are released by crumbling or failure of the cement. Other sands are derived essentially from glacial drift, which in the aggregate contains much sand-sized material. Some of this may have been derived from hard, unrifted rocks without a favorable mineral texture, but much of the larger part probably is derived from granites or other quartz-bearing phanerites, which have yielded with or without incipient crumbling to the scouring action of the glacial ice. So large a proportion of the sand of the continental areas of the world consists of siliceous fragments, and so large a fraction of these consist of the mineral quartz, mostly from granite originally, that the general conclusion stated above seems fully justified. If there are well-sorted sands with widespread occurrence in which the grains are predominantly composed of such material as chert, or of any other mineral or rock not rifted by weathering into favorable sizes, they have not come to general notice.

This state of affairs explains why mature, clean, well-sorted terrigenous stream or beach sands are so rare in Hawaii. Clean calcareous beach sand is abundant along certain coasts of Kauai, Oahu, south Molokai, parts of Maui and probably many other localities, but much less abundant around most of the coastline of the island of Hawaii and other islands of the group. Disregarding this sand of marine, organic origin, the significant sand deposits of Hawaii are restricted to specific localities at each of which there is usually some special explanation of the composition and distinctive character of the sand. More or less permanent small areas or lenses of olivine beach sand are found near Diamond Head, the Koko craters, Manana Island, and Ulupau Head,

[9] Daubrée, A., Études Synthétiques de Géologie Expérimentale, Paris, 1879, p. 251, et seq.

[10] Marshall, P., Wearing of beach gravels: *New Zealand Inst., Trans.*, vol. 58, pp. 512, 517, 1927. Beach sands and gravels: *New Zealand Inst., Trans.*, vol. 60, pp. 344, 345, 349–351, 1929.

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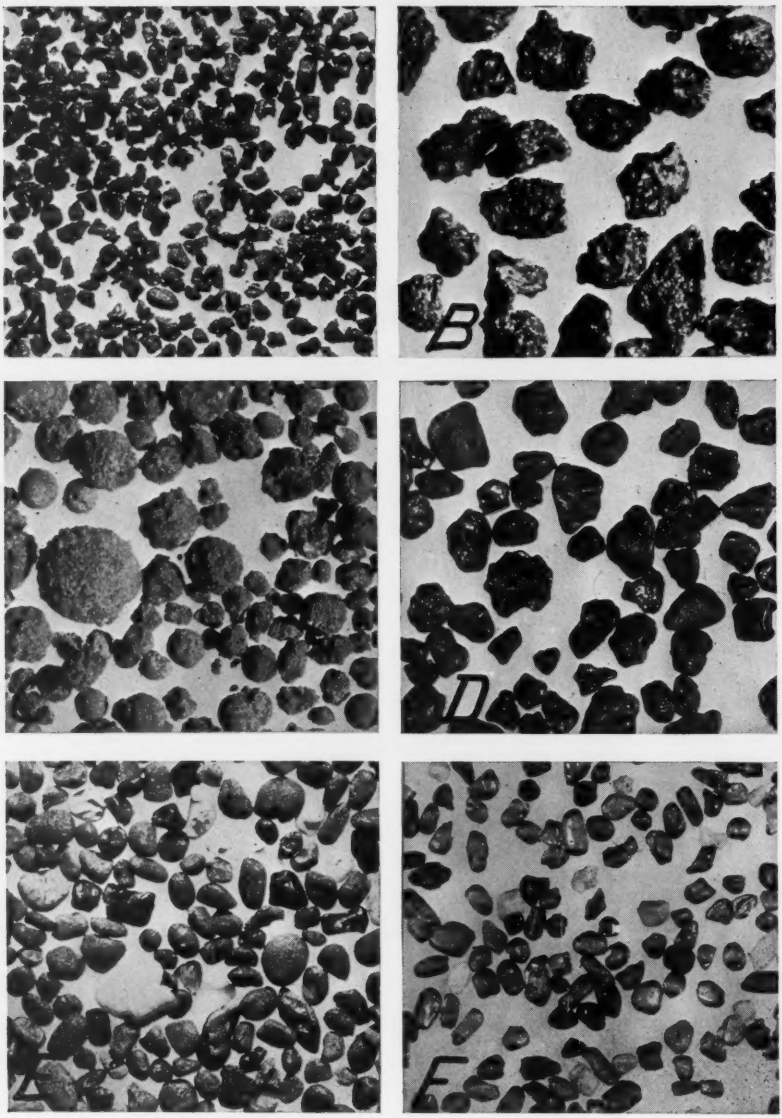

FIG. 1.—(A) Diamond Head black ash, grade 0.500–0.707 mm., from location 495, (×4); (B) same, grade 0.707–1.00 mm., loc. 495, (×8); (C) Separated pisolites from Diamond Head ash, location 496, (×4); (D) Well-battered, relatively dense black glass beach sand, Kaimu (Kalapana), Hawaii, grade 0.500 to 1.00 mm., (×4); (E) Mixed basalt, glass, olivine, shell beach sand, location B.M. 1770, Halawa, Molokai, (×4); (F) Beach sand consisting largely of rounded, well-abraded olivine grains, location 10-B, east of Kalae, Hawaii, (×4).

where the erosion of fairly soft tuff readily releases euhedral olivine crystals of suitable size. Higher density of the olivine than the associated calcareous grains and other minor constituents favors very localized segregation of the olivine to reach as high as 98 or 99 per cent of the deposit.

Some of these sands also contain a considerable number of euhedral augite grains, also from the tuff. With few exceptions the conspicuous olivine sands in Hawaii have been derived by wave action on tuff cones or other types of pyroclastic rock. That limited amounts of olivine may be battered out of glassy, vesicular lavas by wave action, or other processes, such as by horses' hoofs on the Mauna Loa trail, is certain, but these instances are exceptions. Similarly, poorly sorted rill sands composed of olivine are most common on the slopes of tuff cones and are rarely found elsewhere. Tiny streaks of fine-grained magnetite sand are found in places in land rills and where small streams reach the sea. The grains show octahedral forms and are mostly small, falling in the very fine sand grade, or smaller. Specific localities known to the writer on Oahu are in the area where pyroclastic detritus, such as that of the Tantalus-Sugarloaf series, lies over the surface.

There are a few localities in Hawaii where strong wave action on coarse boulder beaches, adjacent to basalt cliffs or headlands, produces small amounts of speckled sand containing fragments of the constituent feldspar, olivine, augite and magnetite of the basalt. None of these show an amount of the sand great enough to imply that important amounts of the sand could be thus produced and rounded to form a distinctive deposit. Marshall has shown that on gravel beaches sand tends to be quickly reduced by grinding and to be removed by wave action so that only small amounts are present at one time. He concludes that beach action does not form significant amounts of sand, and attributes the formation of sand to the action of weathering on granular rocks.[11] A sand and a sandstone containing a dominant percentage of basalt grains, with calcareous grains, and cement, are found on Lanai, near Manele, but such sands or sandstones are extremely rare in Hawaii.

The fact that with some hundreds of miles of coast-line in the Hawaiian Islands from which the writer has collected and preserved many samples, these particular localities are recalled for their types of mineral and terrigenous sands, will indicate the limited amounts of such sand to be found. Mention should be made also of the striking black glass sands of Kaimu (Kalapana), Punaluu and other places on the Kilauea and Mauna Loa coasts of Hawaii, where such sands appear always to be reworked glassy lapilli from littoral cones formed where lava flows have entered the sea and given rise to phreatic eruptions. From this discussion it may be concluded that well-

[11] Marshall, P., Beach gravels and sands: *New Zealand Inst., Trans.*, vol. 60, pp. 344, 345, 349–351, 1929.

sorted, well-rounded sands consisting dominantly of the minerals of basalt and derived by the disruption of basalt are for practical or comparative purposes unknown in Hawaii. Nor is any instance known, or from the facts given above, likely to be found, in which a well-sorted sand consisting of glass particles has been derived from any other source than explosion detritus.

SUMMARY

The weight of evidence contained in the physical and mineral characteristics of the Diamond Head black ash is preponderantly in favor of a pyroclastic origin and direct aeriform emplacement for the formation. Such features include the large proportion of glass, the minutely vesicular texture of much of this glass, its sharp corners and attenuate forms, the presence of Pele's hair, the lack of marks of abrasion or rounding by attrition, the typical mantle bedding, the very small proportion of bedding of clear, wind-produced or dune characteristics, the uniformity of distribution of the small amount of calcareous detritus it contains, the low specific gravity and the high porosity. Finally, the presence of a rather widespread, uniform layer of pisolites is a feature which cannot be explained in any other way. Even without the aerial origin of such accretionary dust balls to contend with, it would still be impossible to explain the deposition of so uniform a layer other than by settling through a fluid, water or air, in this case necessarily the latter. Even if there were available a suitable mass of glass to serve as a parent formation, there are strong presumptions against the production of sand by abrasion from such material, as brought out in the above discussion. Moreover, the placement inland of so pure a dune sand from such a hypothetical beach in limited thicknesses and during a limited time, with no evidence of the occurrence or movement of such sand before or after this presumed drastic invasion, poses another insuperable difficulty of interpretation. The formation is indubitably of pyroclastic origin and emplacement and is stratigraphically younger than at least part of the Black Point lava flow.

We are now, despite the inexcusable failure of the present writer to fully publish his field observations in 1923 and the valiant effort of Stearns to reject the pyroclastic interpretation in 1935, again confronted with the problem of finding the site from which this black ash was blown into the air and dispersed. The distribution of the pisolite layer and the slightly coarser grain of the black ash near the Black Point coast permit us to suppose, but do not definitely prove, that the vent was in that vicinity. The small amount of the material now found suggests a very minor explosive activity. It, therefore, seems reasonable to interpret the black ash as the product of a typical littoral, phreatic eruption produced by the pouring of a lava flow into the sea, or by the emergence of lava from a dike in the shore zone.

This eruption took place when the sea stood at its present level or slightly lower, and hence in post-Waimanalo time. This is not the place to reopen the question of the 12-foot bench and the last eustatic shift of sea level, not fully accepted by Stearns, but if this late emergence of about 12 feet proves to be valid, the black ash eruption must post-date that also and rank as an event of much later geologic time than the earlier Black Point and Diamond Head eruptions.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 3, PP. 104–107, FIGS. 1–4, DECEMBER, 1937

SEDIMENTATION OF COLORADO RIVER IN RUNNELS AND COLEMAN COUNTIES, TEXAS

RAYMOND SIDWELL AND CLARENCE A. COLE
Texas Technological College, Lubbock, Texas

ABSTRACT

The deposits of the Colorado River of Texas consists of clay, sand, pebbles, and boulders. The pebbles and boulders are composed primarily of limestone. The percentage of abrasion of the pebbles is greater than 75 per cent. The abundant minerals are quartz, magnetite, hematite, zircon, tourmaline, rutile, and leucoxene.

The Colorado River flows from a semiarid, through a sub-humid, into a humid region and Coleman and Runnels Counties are located about 100 miles from the source of the stream in the sub-humid part of the course. The source of the Colorado is on the southern portion of the South Plains and it flows from sediments of Tertiary age to and across Triassic and Permian sediments. The chief tributary of the Colorado is the Concho. This has its source on the Edwards plateau and flows from Comanchean across exposures of Permian age.

The region adjoining the Colorado River is known as the Colorado Lowlands. The altitude of these lowlands is about 1,500 feet, but the surface rises to 2,000 feet a few miles back from the stream. The drainage patterns are dendritic, and the tributaries of the Colorado are mainly intermittent. The vegetation over the high areas, consists of bunch grasses, mesquite and catclaw. Conditions over the lowlands adjoining the stream are favorable for the growth of such large trees as pecan, elm, walnut and willow

The rock exposures in Runnels and Coleman Counties are of Permian age and consist primarily of limestones with interbedded shales. The limestones are massive, vary in color from gray to brown, and break into large irregular blocks. The shales are in thin layers a few inches in thickness, vary in color from gray to brown, and contain platy calcareous material.

COLLECTION OF MATERIAL

Samples for study in the laboratory were collected at Coffee, located about 2 miles below the mouth of the Concho River, Curry Bend about 8 miles downstream from Coffee, and Stubbs about 12 miles above Coffee (fig. 1). At each locality material was secured from bottoms of the deeps, bottoms of the shoals, and at various levels above low-water stage. Pebbles were obtained by measuring an area about 3 feet square on the bed of the stream and collecting all pebbles on the area. Water samples, used to determine the amount of suspended matter, were taken at both low and high water stages.

WORK OF THE STREAM

The Colorado River has an older flood plain which is now a terrace about 25 feet above the bed of the present stream. This terrace is underlain by alluvial sediments. The top material consists of interbedded layers of fine sand and dark-colored unconsolidated clay and this grades downward into coarse gravel. Trees, 3 feet in diameter have developed on a terrace indicating that the sediments have not been disturbed by the river for a considerable period of time.

The channel of the present stream is about 300 feet in width and consists of alternating deeps and shoals. The deeps occur chiefly where the channel is straight, but a few deeps are found where the stream makes a gentle curve. They have an average length of about 400 yards and range in depth from 3 to 10 feet. The deposits made in the deeps during low-water stage consist of fine sediments that overlie coarse materials, The sediments about the upper end consist chiefly of sands ranging from 0.5 to 0.25 mm. in diameter, and about the lower end of fine sand, mud, and organic material. The fine sediments are removed from the deeps during flood stage.

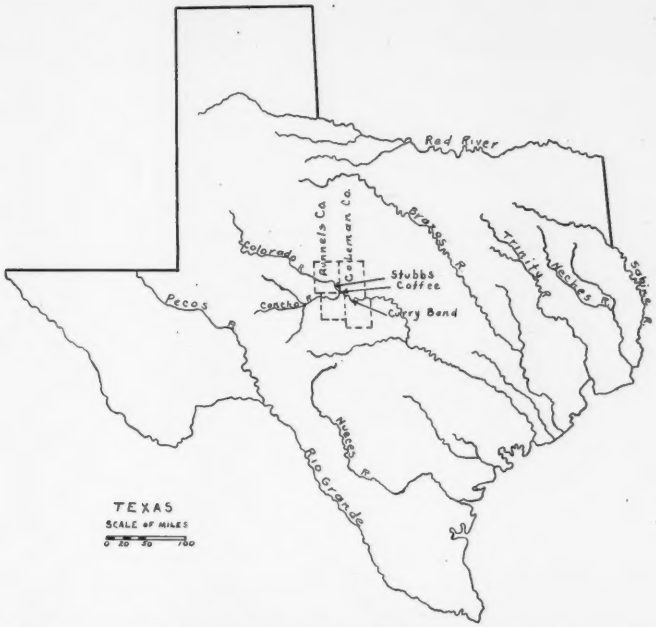

FIG. 1.—Map showing the location of the Colorado River and the portion of the stream described in this report.

The shoals have an average length of approximately one-half mile and occur at the sharp bends. The water in channels over the shoals are narrow, shallow, and braided. The sedi-

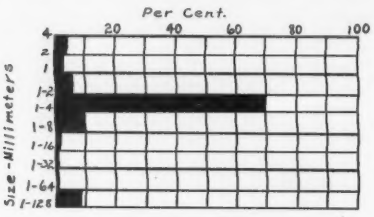

FIG. 2.—Graph showing the texture of the deposits at the upper end of deeps.

ments consist primarily of coarse materials arranged in a series of terraces. With a few exceptions they consist of materials in the range from sand to boulders. The majority of the boulders have been deposited on the concave sides of the bends. Most of the sand and gravel is composed of quartz.

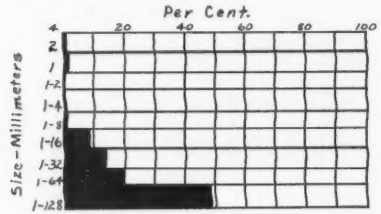

FIG. 3.—Graph showing the texture of the deposits at the lower end of deeps.

During low-water stages, sands and pebbles are transported from the upper end of a shore and deposited in channels at the lower end. During flood stages practically all fine materials are removed from the shoals except in the shallow basins.

CHARACTER OF THE SEDIMENTS

The sediments consist of material in the range from clay to boulders. The boulders consist of limestone, are of local origin, and have a maximum diameter of 6 feet. Boulders that are less than 18 inches in diameter show the greatest amount of wear. Most of the large flat boulders are tilted upstream at an angle often exceeding 10 degrees.

Pebbles ranging in size from 1 to 6 cm. were collected. The larger

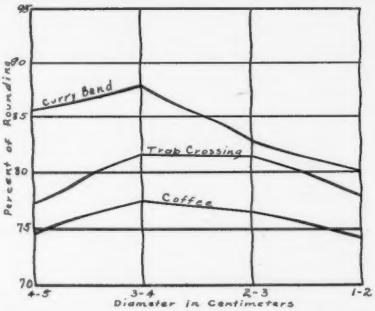

FIG. 4.—Graph showing the per cent of abrasion of the limestone pebbles.

pebbles are composed of limestone, but a few that are less than 3 cm. in diameter, are composed of quartz. The amount of abrasion was determined by the shapometer[1] and the shape was classified according to the percentage of abrasion as used by Tester.[2] In order to obtain a basis for comparison of the limestone pebbles they were divided into 4 groups as

[1] Tester, Allen C., and Bay, H. X., The shapometer: A device for measuring the shapes of pebbles: *Science*, vol. 73, no. 1899, pp. 565, 566, May 22, 1931.

[2] Tester, Allen C., The measurement of the shapes of rock particles: *Jour. Sedimentary Petrology*, vol. 1, pp. 3–11, 1931.

follows: diameters of 4 to 5 cm., 3 to 4 cm., 2 to 3 cm., and 1 to 2 cm. From each group four or five representative pebbles were selected and the abrasion percentage was calculated for each.

As shown in the above figure the maximum wear is on pebbles ranging from 3 to 4 cm. in diameter. At Coffee, the locality farthest upstream, practically all the limestone pebbles could be classed as sub-rounded, with the percentage of abrasion from 61 to 80. At Curry Bend, 11 miles downstream, the limestone pebbles are classified as rounded with the per cent of abrasion above 81.

Most of the quartz pebbles are sub-rounded. A few possess unweathered surfaces and sharp edges. The number and size of the quartz pebbles decrease downstream. Apparently these pebbles were transported from Tertiary deposits near the source of the stream.

Most of the sand was deposited on the downstream sides of obstructions and on the concave sides of the meanders. The sand was sieved to secure the different grades, then separated into light and heavy fractions by means of bromoform. Quartz is the abundant light mineral. Grains larger than 0.25 mm. in diameter are well rounded, but the smaller grains are subangular.

The heavy minerals consist of magnetite, hematite, garnet, tourmaline, rutile, zircon, and leucoxene. The maximum abundance is in the size range from 0.125 to 0.0625 mm. in diameter. Zircon and leucoxene are concentrated in the smaller sizes. The heavy minerals decrease in abundance downstream. In a distance of 11 miles the decrease is about 40 per cent. This suggests that their source is in deposits near the headwaters of the stream.

During a 2 foot rise of the stream a sample of water was secured. When the material settled the water was removed and the weight of the clay was determined. The amount of material carried was 16.5 grams per gallon or 0.27 pounds per cubic foot. Small quantities of clay are deposited in the deeps after floods subside.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 3, PP. 108–109, DECEMBER, 1937

"CAVE PEARLS" IN A CAVE NEAR COLUMBIA, MISSOURI

W. D. KELLER
University of Missouri, Columbia, Missouri

ABSTRACT

The occurrence of "cave pearls" in a cave near Columbia, Mo., is described. Growth on the upper (rough) surface is chiefly through an accretion of precipitated calcium carbonate grains, whereas the underside (smooth) grows by crystal growth. The growth rate of the former exceeds that of the latter.

Reports of the occurrences[1] of oolites and pisolites in the process of formation in caves are so scanty that the impression may be gathered that these occurrences are uncommon. Probably such impression is erroneous; perhaps the localities simply have not been reported.

The writer wishes to place on record the occurrence of "cave pearls" in a cave known as the Holton Cave which is about 5 miles northwest of Columbia, Boone County, Mo. The cave lies about one-half mile from a poorly maintained county dirt road which is graveled about 2 miles out of Columbia.

The country rock of the region is the coarse-grained, highly fossiliferous, crinoidal, Burlington limestone of Mississippian age. It is a calcite limestone, rather pure except for its content of chert nodules, and although intrinsically soluble has caves and sink-holes developed in it only in restricted areas.

The Holton cave is a typical solution cave with roof about 8 feet in height and walls about 15 feet apart near the entrance, but narrows in cross section toward the back so as to hinder exploration within about a quarter mile. A permanent stream flows throughout its explored length and is added to by seeps and drips from the walls and roof. Stalactites and stalagmites are present, but not abundantly developed.

The "cave pearls" occur and are being formed on a terrace within 100 feet of the entrance. A strong seep, aided by occasionally dripping water from the roof, has deposited fibrous and spongy crusts of calcium carbonate in a convex form over a stream bank. Small carbonate dams which are grown over the surface form the lower side of reservoirs or cups a few square inches in area and a fraction of to an inch in depth. It is in these cups that the "cave pearls" are found.

The "pearls" are oolites and pisolites (over 2 mm. in diameter),[2] most of which show in thin section a fibrous radial structure. They are spherical to elliptical in shape, in

[1] Hess, F. L., Oolites or cave pearls in the Carlsbad Caverns: *U. S. Nat. Mus., Proc.*, no. 2813, vol. 76, pp. 1–5, 1929.
Davidson, S. C., and McKinstry, H. E., "Cave Pearls," Oolites and isolated inclusions in veins: *Econ. Geology*, vol. 26, pp. 289–294, 1931.

[2] Twenhofel, W. H., Treatise on sedimentation, Williams and Wilkins Co., p. 757, 1932.

some instances curvilinear polyhedral, and range in size up to about 15 mm. in diameter. In spite of the predominant radial growth, which is diagnostic of spherulites,[3] concentric color bands were always seen in their thin sections, thereby retaining them in the oolite group.

Mineralogically, the "pearls" are calcite, although quartz may be present in the nucleus as a single grain or as several small grains held in a carbonate aggregate or floccule. In other instances the nuclei are fine-grained carbonate floccules sometimes stained dark with organic matter, and occasionally the center of growth seems to be only a simple speck of carbonaceous material.

At the time of the first draft of this note, spring of 1935, a tentative observation, subsequently verified, was made regarding the surface pattern of the pearls. It was noticed that presumably the flatter, or more lens-shaped particles ordinarily had a grainy, rough, upper surface which commonly overhung slightly that part below the near-midsection, whereas the lower surface was smoother, or even somewhat polished. Likewise, the part covered by the rough surface was thicker than that which was smooth. Some speculation on the reason for this occurrence was made at that time, but was withheld pending further study.

At the present time, two years later, an additional statistical examination of a later formed crop of the pearls increases the weight of evidence to a point of security in making a generalization of the description just given. It supports also the observation that the more nearly spherical bodies possess a more uniform grainy surface over-all than the elliptical ones do. The cause for the difference appears to be as follows.

In the case of an elliptical shaped pearl the chances are great that it will not be turned over by the splash and weak currents of water, but will remain and grow in a relatively fixed position. While lying in this position the fine particles of carbonate which precipitate out of the water because of evaporation, gas loss, and agitation, will settle and accumulate as a growth upon the upper surfaces of the pearls. This relatively rapid accumulation accounts for the thickened, porous, granular and rough upper parts, and the overhang over the lower. The lower parts of the pearls are added to merely by crystal growth on the solid from solution and therefore are thinner. Their surfaces are developed smoother or somewhat polished for the same reason.

The spherical pearls, on the other hand, receive a more uniform addition of both grains and crystal growth over their entire surfaces because they are easily turned and rolled about by the currents and water splash. Hence, their surfaces will be uniformly grainy, contrasting with those on the elliptical pearls.

Perhaps these notes on growth will indicate a reason for the difference in opinions expressed by earlier writers on the question of rolling of cave pearls during their growth.

[3] Loc. cit.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 3, PP. 110–132, FIGS. 1–5, DECEMBER, 1937

THE USE OF STATISTICAL METHODS IN EFFECTING IMPROVEMENTS ON A JONES *SAMPLE SPLITTER**

GEORGE H. OTTO
Soil Conservation Service, Cooperative Laboratory, California Institute of Technology,
Pasadena, California

ABSTRACT

An improved Jones sample splitter is described which is faster to operate than the conventional type, yet requires no special skill or training. Samples obtained with this instrument are free from the occasional erratic samples obtained with ordinary Jones sample splitters. Working drawings are given for this improved sample splitter, which can be built with hand tools.

The sample splitter was tested with small gravel, granules, and sand in which the percentage of each constituent was accurately known. Three series of 24 samples each were taken and sieved; in each series one detail of technique was varied. The components separated by sieving were returned to the original mixture in each test to keep the conditions of the experiment nearly constant. Summarized instruction are given for the best technique of operation.

The second part of the paper deals with methods used to measure the performance of the improved sample splitter. The concept of a state of control is discussed. The calculations required to detect lack of constancy in the chance cause system, biased percentages, or the presence of a predominating cause of variation are shown. The principle that variability in comparable series of samples tends to diminish as the state of control is approached was found to apply in the present study.

These methods of statistical analysis are very general and may be applied to field sampling studies or wherever quantitative measurements are made on a series of samples suspected of coming from an essentially homogeneous unit or constant chance cause system.

PART I—INTRODUCTION

The Cooperative Laboratory of the Soil Conservation Service at California Institute of Technology carries on frequent hydraulic experiments which involve the mechanical analysis of sediments. Often a small change in composition is known to have occurred. A quantitative knowledge of the errors involved is required. The quantity of sediment is such that "field" errors are of the same order of magnitude as laboratory errors. Effective study of the sampling errors demands that the laboratory errors be known. Consequently, the sample splitting problem was selected for detailed study.

Mining engineering literature contains numerous references to various devices (7) for obtaining representative samples of ores for chemical analysis. Most of these devices include moving parts and were developed for continuous sampling of streams of ore coming from crushers. They are usually operated in tandem, the sample being crushed between each successive reduction. Such devices as the Vezin sampler (1) and the Brunton time sampler (2, 3) are typical of those intended for continuous feeds. They employ the principle of taking "all the stream part of the time."

* Published with permission of the Soil Conservation Service, U. S. Dept. of Agriculture.

No record of extensive tests was found in any of the references describing the Jones sample splitter (9) or modifications of it. The theory, as it applies to ore sampling, is discussed by Brunton (4). Sampling for mechanical analysis offers a difficulty not encountered in mining sampling: the sample cannot be crushed at any stage of the reduction. This difficulty may be overcome by choosing a field sample with a number of particles just large enough to represent the rarest or coarsest component under study. Wentworth discusses this procedure (12). Laboratory sampling and sieving errors also were investigated by Wentworth (13).

The sample splitting plan used by Wentworth differs from the practice of most operators who habitually interchange the contents of the pan on the right side with the just emptied pouring pan or scoop. Consequently, it seems preferable in a study of different techniques of operation, or of the efficiency of two or more instruments, to take each sample in exactly the same manner. Furthermore, it is desirable that the sieved material be replaced before the next sample is split off. The resulting variability, if enough samples are taken, is then a reliable measure of the amount of deviation from the average to be expected in single samples of similar sediments.

CHARACTERISTICS OF AN EFFICIENT LABORATORY SAMPLE SPLITTER

A certain amount of variation in any series of samples is to be expected. Even if all the particles were the same size, shape, density, and elasticity and differed only in some characteristic such as color, the samples would not have the same percentage of particles of each color every time. But if the number of particles of each color were very large and the samples were large, the resulting percentages of each color would show little variation with almost any sample selecting device. In such cases and even for small samples it is possible to calculate, without recourse to experiment, the important mathematical properties, or statistics, of a large number of samples.

In ordinary mechanical analyses, frequencies are expressed in per cent by weight. A single extra pebble therefore has a far greater influence than a single extra sand grain. Because the particles are irregular in shape and because average shape characteristics are seldom quantitatively known, the problem of calculating the variation to be expected in a large series of samples cannot be solved without recourse to experiment. Furthermore, number frequencies are not usually a practical medium for expressing mechanical analyses because of the extraordinarily low frequencies of the coarser particles and the uncertainty regarding the total number present.

Thus for ordinary sediments efficiency cannot be measured by comparing statistics derived from experimental tests with a set of calculated values. Let an experiment be devised, however, in which all errors except the sample splitting error are

relatively unimportant and in which the experimental set-up closely simulates conditions in practice; let measurements be made on each of a number of samples. Such data will not only furnish the basic information for determining the empirical performance characteristics of the instrument, but will also go far toward answering the question, "Can the performance be considerably improved without altering the basic principles of design or operation?" The technique of analyzing such data and the reasoning leading to the actual improvements are discussed in part II.

An efficient laboratory sample splitter should be convenient to operate and should give dependable results under a wide variety of conditions. These characteristics may be classified as follows:

A. Performance characteristics

1. If some quantitative measurement be made on each of a large number of samples, and if the errors of the measurement are small compared with the sampling errors, the number of values lying within a symmetric range of *the average value* (arithmetic mean) *should be predictable.* The symmetric range is ordinarily expressed as some multiple of the standard deviation[1] of the values.

The practical importance of this property of an efficient sample splitter is as follows: Suppose that one laboratory sample is split off from each of two field samples (part of a suspected variation series), and that the two samples show a small difference in some measured characteristic. If an estimate is available for the standard deviation of this characteristic in samples obtained with the sample splitter, it is possible to say whether the difference may reasonably be attributed to sampling fluctuations alone. If it is known, however, that the distribution of a large number of samples is not approximately predictable, limits to the fluctuations cannot be assigned with any assurance.

2. The average value of any measurable characteristic determined for each of a series of samples should approach the true value as the number of samples is increased.

3. Different operators should obtain essentially the same average values.

4. Different operators should obtain essentially the same dispersion of values about their averages.

5. The materials to be sampled must not tend to clog the instrument.

B. Convenience characteristics

1. The sample splitter should be capable of handling dry gravel passing a 16 mm. sieve and all smaller sizes of dry material. An instrument capable of handling coarser material is too unwieldy for small samples of fine sands.

2. The pans should hold approximately four kilograms of sand. Larger capacities make the pans hard to manipulate; smaller capacities are insufficient for pebbly sands and fine gravels, even after removing the coarsest sizes from the entire field sample.

3. No special training or skill should be required.

4. The sample splitter should be ruggedly constructed and preferably free from moving parts.

5. The design should prevent unnecessary losses.

6. The instrument should be capable of rapid operation and easy cleaning.

7. An instrument which can be built from readily available materials and ordinary hand tools is desirable.

CONSTRUCTION OF THE IMPROVED JONES SAMPLE SPLITTER

A study of many types of sample splitters showed that those with

[1] The standard deviation, denoted by σ, is defined by the equation

$$\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{N}}$$

where $(X - \bar{X})^2$ is the square of the deviation of an observed value, X, from the arithmetic mean value of the group and N is the number of measurements.

moving parts are not well adapted to the intermittent feeds and small samples necessarily encountered in the last stages of sample reduction. The Jones type seemed to offer the most promise, despite an inherent defect in the method of taking the sample: it belongs to that class of sample splitters which take "part of the stream all of the time." This principle is considered inferior to that used in the Vezin and Brunton samplers because the necessary divisors produce marked segregations in the stream of material passing by them. A slight injury to the divisor, or a defect in the construction, or a piece of fibrous material accidentally lodged on a divisor may divert too many coarse particles to one side. The Jones splitter minimizes this error by introducing an even number of chutes, usually 12 to 18, and allowing the streams from alternate chutes to be included in the sample. One abnormal end-fraction goes to each side. Each passage through the instrument reduces the sample to one-half the previous size.

The sample splitter shown in figure 1 was used in all the later experiments and will be called the *improved sample splitter*. It has proved thoroughly satisfactory for a variety of sediments and conforms to the requirements outlined above.

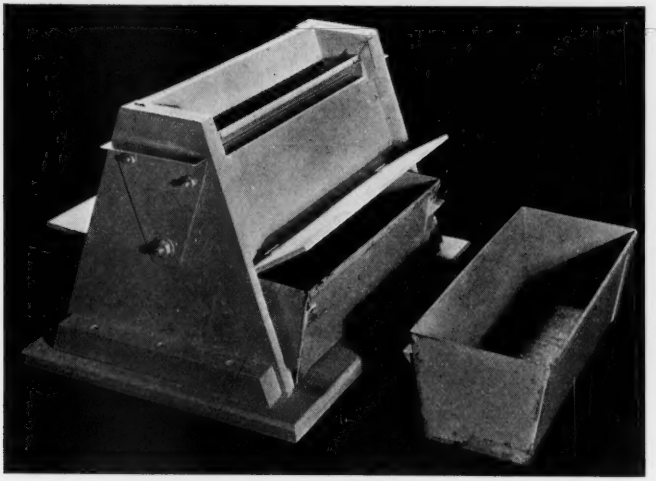

FIG. 1.—Improved Jones sample splitter.

The instrument consists of the splitter proper and three identical pans. No scoop is required. The manner of operation is essentially the same as for the Taylor and Brunton sample splitter (3). Although it differs from the conventional Jones sample splitter in appearance, the

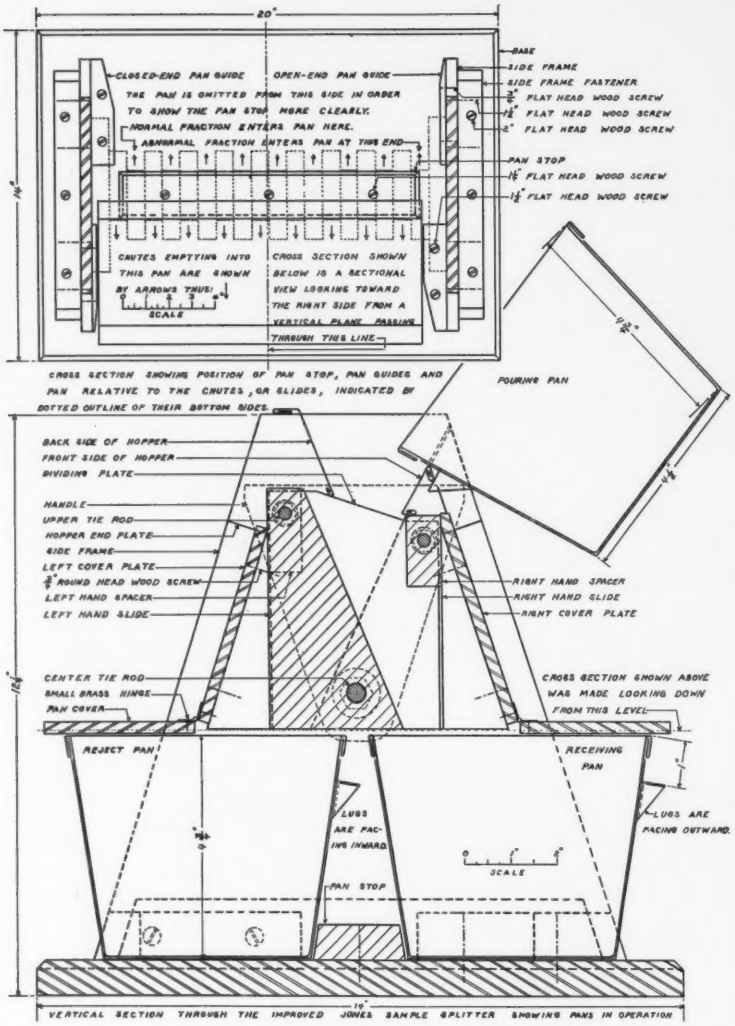
20"
BASE
SIDE FRAME
SIDE FRAME FASTENER
⅜" FLAT HEAD WOOD SCREW
1½" FLAT HEAD WOOD SCREW
2" FLAT HEAD WOOD SCREW
PAN STOP
1½" FLAT HEAD WOOD SCREW
1½" FLAT HEAD WOOD SCREW
CLOSED-END PAN GUIDE
OPEN-END PAN GUIDE
THE PAN IS OMITTED FROM THIS SIDE IN ORDER TO SHOW THE PAN STOP MORE CLEARLY.
NORMAL FRACTION ENTERS PAN HERE.
ABNORMAL FRACTION ENTERS PAN AT THIS END
CHUTES EMPTYING INTO THIS PAN ARE SHOWN BY ARROWS THUS:
SCALE
CROSS SECTION SHOWN BELOW IS A SECTIONAL VIEW LOOKING TOWARD THE RIGHT SIDE FROM A VERTICAL PLANE PASSING THROUGH THIS LINE
CROSS SECTION SHOWING POSITION OF PAN STOP, PAN GUIDES AND PAN RELATIVE TO THE CHUTES, OR SLIDES, INDICATED BY DOTTED OUTLINE OF THEIR BOTTOM SIDES.
POURING PAN
BACK SIDE OF HOPPER
FRONT SIDE OF HOPPER
DIVIDING PLATE
HANDLE
UPPER TIE ROD
HOPPER END PLATE
SIDE FRAME
LEFT COVER PLATE
⅜" ROUND HEAD WOOD SCREW
LEFT HAND SPACER
LEFT HAND SLIDE
RIGHT HAND SPACER
RIGHT HAND SLIDE
RIGHT COVER PLATE
CENTER TIE ROD
SMALL BRASS HINGE
PAN COVER
CROSS SECTION SHOWN ABOVE WAS MADE LOOKING DOWN FROM THIS LEVEL
REJECT PAN
RECEIVING PAN
LUGS ARE FACING INWARD
LUGS ARE FACING OUTWARD
SCALE
PAN STOP
VERTICAL SECTION THROUGH THE IMPROVED JONES SAMPLE SPLITTER SHOWING PANS IN OPERATION

FIG. 2.—Assembly drawing of improved Jones sample splitter.

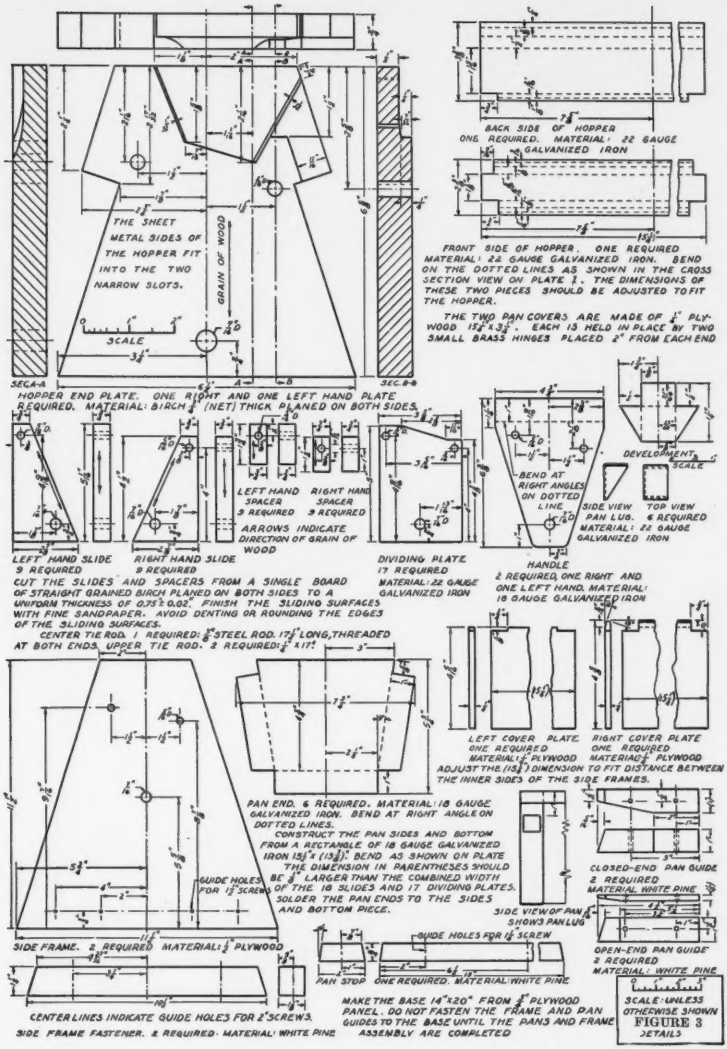
BACK SIDE OF HOPPER
ONE REQUIRED. MATERIAL: 22 GAUGE GALVANIZED IRON
FRONT SIDE OF HOPPER. ONE REQUIRED MATERIAL: 22 GAUGE GALVANIZED IRON. BEND ON THE DOTTED LINES AS SHOWN IN THE CROSS SECTION VIEW ON PLATE I. THE DIMENSIONS OF THESE TWO PIECES SHOULD BE ADJUSTED TO FIT THE HOPPER.
THE TWO PAN COVERS ARE MADE OF ¼" PLYWOOD 15½" × 3½". EACH IS HELD IN PLACE BY TWO SMALL BRASS HINGES PLACED 2" FROM EACH END
THE SHEET METAL SIDES OF THE HOPPER FIT INTO THE TWO NARROW SLOTS.
GRAIN OF WOOD
SCALE
SEC. A-A
SEC. B-B
HOPPER END PLATE. ONE RIGHT AND ONE LEFT HAND PLATE REQUIRED. MATERIAL: BIRCH ¾" (NET) THICK PLANED ON BOTH SIDES.
DEVELOPMENT
SCALE
BEND AT RIGHT ANGLES ON DOTTED LINE
SIDE VIEW
TOP VIEW
PAN LUG. 6 REQUIRED MATERIAL: 22 GAUGE GALVANIZED IRON
LEFT HAND SPACER 9 REQUIRED
RIGHT HAND SPACER 9 REQUIRED
ARROWS INDICATE DIRECTION OF GRAIN OF WOOD
LEFT HAND SLIDE 9 REQUIRED
RIGHT HAND SLIDE 9 REQUIRED
DIVIDING PLATE 17 REQUIRED MATERIAL: 22 GAUGE GALVANIZED IRON
HANDLE 2 REQUIRED, ONE RIGHT AND ONE LEFT HAND. MATERIAL: 18 GAUGE GALVANIZED IRON
CUT THE SLIDES AND SPACERS FROM A SINGLE BOARD OF STRAIGHT GRAINED BIRCH PLANED ON BOTH SIDES TO A UNIFORM THICKNESS OF 0.75" ± 0.02". FINISH THE SLIDING SURFACES WITH FINE SANDPAPER. AVOID DENTING OR ROUNDING THE EDGES OF THE SLIDING SURFACES.
CENTER TIE ROD. 1 REQUIRED: ⅜" STEEL ROD. 17" LONG, THREADED AT BOTH ENDS. UPPER TIE ROD. 2 REQUIRED: ¼" × 1¼" × 3"
LEFT COVER PLATE ONE REQUIRED MATERIAL: ¼" PLYWOOD
RIGHT COVER PLATE ONE REQUIRED MATERIAL: ¼" PLYWOOD
ADJUST THE 15¾" DIMENSION TO FIT DISTANCE BETWEEN THE INNER SIDES OF THE SIDE FRAMES.
PAN END. 6 REQUIRED. MATERIAL: 18 GAUGE GALVANIZED IRON. BEND AT RIGHT ANGLE ON DOTTED LINES.
CONSTRUCT THE PAN SIDES AND BOTTOM FROM A RECTANGLE OF 18 GAUGE GALVANIZED IRON 13½" × 13½". BEND AS SHOWN ON PLATE I. THE DIMENSION IN PARENTHESES SHOULD BE ¾" LARGER THAN THE COMBINED WIDTH OF THE 18 SLIDES AND 17 DIVIDING PLATES. SOLDER THE PAN ENDS TO THE SIDES AND BOTTOM PIECE.
GUIDE HOLES FOR ¼" SCREWS
SIDE VIEW OF PAN SHOWS PAN LUG
CLOSED-END PAN GUIDE 2 REQUIRED MATERIAL WHITE PINE
OPEN-END PAN GUIDE 2 REQUIRED MATERIAL: WHITE PINE
SIDE FRAME. 2 REQUIRED MATERIAL: ¾" PLYWOOD
GUIDE HOLES FOR ¼" SCREW
PAN STOP ONE REQUIRED MATERIAL: WHITE PINE
CENTER LINES INDICATE GUIDE HOLES FOR 2" SCREWS.
SIDE FRAME FASTENER. 2 REQUIRED. MATERIAL: WHITE PINE
MAKE THE BASE 14" × 20" FROM ¾" PLYWOOD PANEL. DO NOT FASTEN THE FRAME AND PAN GUIDES TO THE BASE UNTIL THE PANS AND FRAME ASSEMBLY ARE COMPLETED
SCALE: UNLESS OTHERWISE SHOWN
FIGURE 3
DETAILS

FIG. 3.—Details of construction of the improved Jones sample splitter.

principle of operation is the same.

The improved sample splitter possesses a number of refinements which eliminate errors and greatly reduce the personal element in the operation. Figure 2 shows a cross section through the middle with the pans in operating positions. The designations used in the text for referring to the different pan positions are shown. Figure 3 shows detail drawings of the parts.

The pans are constructed of 18-gauge galvanized iron with reinforced pouring edges. Guide lugs are provided at each end of one side. The pouring pan is placed with the top side of these lugs against the lower hopper rim; in this way the pouring edge is always at right angles to the dividing plates and the pan is always emptied from exactly the same place and side. The overall width of the pans is one-fourth inch longer than the combined width of the chutes and dividing plates. The pans fit closely in the hopper and so are always correctly centered.

The splitter consists of a short hopper section, chutes called slides, partitions called dividing plates, a frame, and receiving pan spacers.

The end plates of the hopper section are made of birch. The irregular shape provides clearances for the pans and a support for the dust covers. The front and back sides of the hopper are made of 22-gauge galvanized iron. The front side of the hopper serves as a pan rest. It is purposely built close to the dividing plates, just high enough to provide safe clearances.

Taller hoppers raise more dust and cause more wear on the sliding surfaces; gravel tends to injure the dividing plates because of stronger impacts. Tall hoppers also give the grains more opportunity to sort when there is any irregularity in the method of sample introduction. Nearly all commercial splitters have a much higher hopper, not for holding material, but presumably to serve as a mixing chamber. If the sample is very poorly mixed, desirable mixing may take place; but if the pouring edge of the pan is not exactly at right angles to the dividing plates, this extra space will accentuate the tendency to throw too much coarse material to one side.

The hopper is also narrower than in most splitters. As a result, the back side of the dividing plates had to be raised and the chutes sloping toward the pouring side had to be made steeper than the others to prevent certain sizes of grains rebounding into the other chutes. The improved splitter eliminates this error completely.

The chutes or slides are made of birch of uniform thickness and planed on both sides, with the grain of the wood parallel to the sliding edge. The sliding surfaces should be smoothly finished and should have edges free from dents in order that grains will not lodge along the contact with the dividing plate.

The dividing plates forming the partitions between the chutes are made of 22-gauge galvanized iron with the dividing edges sharpened somewhat. They show little wear after long-continued use on angular gravel.

The frame is constructed of plywood with short handles of heavy galvanized iron at each end. The parts are held together by three steel rods threaded at both ends.

The receiving pan spacers are designed to space the pans automatically with equal overlap on each end of the last open chute. They should not be fastened until the pans have been completed and the rest of the instrument has been fitted to the base.

TESTS ON THE IMPROVED SAMPLE SPLITTER

The tests on the improved sample splitter were designed to eliminate sieving errors and to detect biased percentages. Two mixtures were used. Their composition and the nature of their size distribution are shown by the histograms in Fig. 4.

The *coarse mixture* consisted of commercial pea gravel, a granule (11) concentrate, and sand; it weighed 5.6 kilograms.

The *fine mixture* consisted of a granule concentrate, coarse sand from dune ripple crests, and fine dune sand; it weighed 4.3 kilograms.

The six parent materials were screened to remove particles outside the desired ranges, were washed to remove adhering fines, and were dried. Samples of appropriate size were split off from each of the six components and were analyzed by sieving, using a complete set of sieves. All of each component not used in the sieve analysis was weighed and used in the mixture.

Each of the six analyses is subject to the usual errors. But because the distributions of particle sizes in the components have almost no overlap, the percentages passing sieves located at the minimum grades can be very accurately measured from the weight of each of the three components of the mixtures. Consequently, using only the two sieves at the minimum grades and a pan, separations can be made in which the sieving error is negligible.

The use of such irregular distributions of particle sizes no doubt increases sampling difficulties. Since the purpose of the tests was to detect defects in the instrument, the use of such distributions is justified.

The components of the coarse mixture showed an extreme tendency to separate whenever the mixture was jarred or poured from one container to another. The best mixing was obtained by repeatedly pouring the sample through the splitter until only a small fraction was caught in the receiving pan. The reject pan and the pouring pan were now interchanged and the process repeated twice more. This procedure was used at the beginning of each series of runs with the coarse material. The components of the fine mixture were easily mixed by being poured four times from the end of one pan into the middle of another.

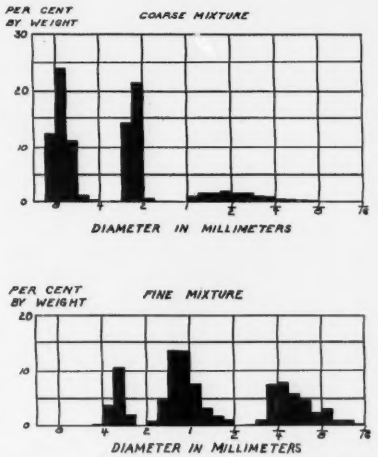

FIG. 4.—Histograms of mechanical analysis of the mixtures used in the sampling experiments.

For the coarse mixture 3 series of 24 analyses each were made as follows:

A sample one-sixteenth of the original was obtained by four passages through the splitter in the usual manner. This sample was weighed and sieved by hand shaking for about one minute. The separations were so sharp and rapid that the use of a mechanical shaker was unnecessary. Only the 3.33 and 0.991 mm. sieves and pan were used. The weighed separates were returned before the next sample was split off.

In all cases the receiving pan was placed beneath the pouring side of the hopper. Thus

every sample in each series was subjected to an essentially constant technique.

The first series of 24 samples was run with the receiving pan lugs facing inward at all times. The second series was run with the receiving pan lugs facing outward. The third series was run with the lugs facing alternately out and in, starting every time with the lugs out. This procedure was found to eliminate a bias which was present in both the other cases. It also decreased the dispersion in the sample weights and percentages.

pan. Weighings were made to the nearest centigram. The separations were complete with only 20 seconds of vigorous shaking.

In order to obtain a measure of the improvements effected in the present design over a good commercially obtainable instrument, a series of 24 tests was run on the splitter shown in figure 5 using the fine mixture. The method of operation pictured in the trade catalog gave unsatisfactory results on a few preliminary tests. Some variations were tried without success.

FIG. 5.—Commercial sample splitter used in tests.

The pan used to collect the rejected portion of the sample was placed with lugs facing inward at all times. Because this pan becomes the pouring pan at the start of the next sampling operation, it was desirable to keep the same arrangement of the particles relative to the pouring side. In ordinary work, where only a single sample is taken, either way is equally satisfactory.

Only one series of 24 analyses was run using the fine mixture. The lugs on the receiving pan were placed outward; a bias resulted which was much smaller than with the coarse material. All the measures of variation showed smaller values as would be expected from the larger number of particles present on each sieve. The samples were one-thirty-second of the original; they were sieved by hand shaking using the 1.98 and 0.417 mm. sieves and the

A method using the scoop instead of the pan for pouring gave the best results. A kilogram, or preferably less, of the well-mixed material was carefully emptied onto the central part of the scoop and spread out somewhat, preserving about equal amounts on each side of the center line of the scoop. The scoop was then tilted gently and vibrated twice a second between the ends of the hopper until all the material on the

scoop had passed through the splitter. It is important to keep the pouring edge at right angles to the dividing plates. The oscillation will cause the angle to vary somewhat during each vibration, but there will be less danger of introducing a bias in the percentages than if the scoop were held in a fixed position. The method is time consuming for large amounts of material. So much material of certain sizes bounced out of the pans, or did not enter, that it was collected every time and returned, lest a bias not properly chargeable to the device enter into the results. Such losses were so small on the improved splitter that the few grams recovered were returned only after the twelfth and twenty-fourth samples.

The sampler used in the above tests was not intended for material as coarse as commercial pea gravel and so no tests were made on the coarse mixture. There are 18 chutes just as in the improved splitter, but the chutes are only one-half inch wide. The narrower size is commonly considered preferable for such materials as the fine mixture. Perhaps the larger number of chutes usually used in the narrower sizes is the main cause of the apparent superiority.

Details of the analytical results are discussed in the second part of this paper, and supported by tables which will be referred to later.

SUMMARIZED TECHNIQUE FOR THE IMPROVED JONES SAMPLE SPLITTER

1. Pour the material to be sampled, which should be dry and free from lumps, into one of the pans. Level off the material in the pan.

2. Place a pan with lugs outward under the pouring side of the hopper and against the pan stop. Place another pan against the pan stop on the other side to receive the rejected material as shown on figure 2.

3. Close the covers.

4. Place the top side of the lugs of the pouring pan against the under side of the hopper rim on the lower side of the hopper as shown on figure 2.

5. Rotate the pan using the hopper rim as a fulcrum until all the material has been emptied. Keep the lugs against the hopper rim. Tap the pan lightly with a small wood mallet if the material is dusty.

6. Exchange the now empty pan with the receiving pan, putting the lugs inward this time and repeat as before.

7. Continue until the sample has been reduced to the required size, taking care to reverse the position of the lugs each time an empty receiving pan is put in place.

In refined work on sands free from gravel, better results are obtained if the field sample is first mixed by pouring four times out of the end of one pan into the middle of another before leveling and splitting. When much gravel is present segregation appears to be increased; it is then better to empty the field sample into the middle of the pan and to pass the sample through the instrument several times.

To sample clays or silts crush the air-dried or preferably slightly damp material to pass a 2 mm. sieve. If the crushed material is slightly damp and the covers are kept closed a half minute after each passage, dust losses will be small. Some material tends to adhere to the slides and other surfaces. Remove it by giving the splitter several sharp taps at each end on

the metal plate surface between the three tie rods.

Whenever the quantity of material in the receiving pan is small, withdraw the pan carefully and collect the material along the bottom edge nearest the lugs. Do not allow the material to slide toward either end. If a sample has been removed from the pan and found to be too large, split off a new one the correct size; do not pass the previous sample once more through the splitter.

PART II—STATISTICAL ANALYSIS OF THE DATA

The quantitative data presented in the preceding section do not, without further study, reveal whether it is reasonable to suppose: (1) that the improved sample splitter possesses superiority over the other instrument except in convenience, speed of operation and larger capacity; (2) that the improved sample splitter can be expected to continue to give results with small dispersion; (3) that the frequency with which a value may be expected to lie within a symmetrical range of the average can be approximately predicted; (4) that the average values are not biased; (5) that some minor changes in design (without changing the basic principle) might be made which would effect a large reduction in the errors.

Careful inspection of the data yielded little information not shown by a cursory inspection. Plotting the percentages for each series on a triangular diagram revealed some differences in the distribution pattern. Plotting the sample weights against the percentages suggested relationships in some cases.

A quantitative study, based on the mathematical theory of small samples, proved to be the most effective method of analysis. Additional time required for calculation was compensated by shorter time required for locating sources of error.

The methods to be presented are applicable to any study based on samples. They furnish a new approach to the study of efficient field sampling methods. The Cooperative Laboratory has begun such a study of the field sampling of beach and dune sands for mechanical analysis. Enough has been done to demonstrate the value of the methods and of the reasoning on which they are based.

The methods and reasoning presented have been adapted from Shewhart (10); the following sections summarize some of the concepts used by Shewhart in developing his statistical techniques.

THE CONCEPT OF A STATE OF CONTROL

Let the reader write some letter of the alphabet such as *d*; now try and make 29 more as nearly alike as possible. Examine them carefully. They will not all be alike in height, width, shape, area enclosed or any one of a number of characteristics. Thus what were intended to be exact duplicates are found to possess *variability* when closely examined. Now let two other people repeat the experiment. Each person's *d*'s will show differences among themselves, yet it is possible to distinguish the group made by one person from the group made by another, because each group varies *within limits*. The environ-

ment under which each person produced his series of letters was controlled. The *attributes* or *qualities* of each person's *d*'s are also said to be *controlled*.

If this simple experiment be repeated tomorrow, under conditions as nearly alike as possible, the variability to be expected in each person's *d*'s can be predicted from a knowledge of the variability observed in those already made. This is the third attribute of a *controlled quality*. A phenomenon may be said to be controlled when its future variability can be predicted, at least within limits, from a knowledge of its past variability. *Prediction within limits* means that the probability that the observed phenomenon will fall within given limits can be stated approximately.

These concepts are equally applicable to the much more involved problem of taking a sample of beach sand in such a way that measurements on a series of samples taken in the same way would be controlled; or to the problem of taking a single laboratory sample for sieve analysis in such a manner that measurements on a series of similar samples would be controlled.

THE CONCEPT OF A CONSTANT CHANCE CAUSE SYSTEM

Many measurements made in everyday work show such small fluctuations when made repeatedly that ordinarily only a single measurement is taken. Examples are the length of a rod, the weight of a metal bar or the density of a single crystal. Even here, precise determinations are subject to many errors.

Other measurements such as the density of granite determined on a series of samples from the same intrusive mass are subject to a larger relative variation. Detailed microscopic study would reveal many of the causes of variation, but there would still remain some unexplained fluctuations resulting from unknown or *chance causes*.

Much greater variability is ordinarily encountered in quantitative work on sediments. Consider a series of pebble counts of the proportion of a certain kind of rock in 2-kilogram samples of gravel taken at 10-meter intervals on a gravel beach. Many variations of the proportion in the samples will remain unexplained even after a detailed study of the field conditions. If the samples are taken from a more limited area of the beach, a relatively larger amount of the variation will be unexplained. (The absolute amount of variation will usually be smaller.) Again this variation results from a complex system of unknown or *chance causes*.

Three postulates regarding these chance cause systems require brief consideration:

1. Some chance cause systems are such that the future can be predicted in terms of the past. On the pebble beach, if a second series of samples were taken between each of the samples in the first series, the number of samples with proportions between given limits could be approximately predicted. (Note that this is very different from saying that the

proportion in each sample could be predicted.) However, no prediction would be expected to hold true one month later; the wind and waves constitute chance causes of such a nature that quantitative prediction is not possible. Off-shore winds might bury the pebbles beneath a layer of wind blown sand; the waves might build a sand beach over the pebble beach; a major storm might remove all the smaller pebbles and leave a cobble beach.

Statistical methods furnish a powerful tool for discovering which chance cause systems give rise to predictable phenomena.

2. Constant systems of chance causes exist in nature. The till deposited by continental ice sheets is the result of such a cause system. Despite the very complex nature of the factors or causes which determine the composition of the till at a particular location, it is possible when studying regional variations to take single samples at random from topographically comparable locations for study (6). This would not be possible if the resultant of these complex causes were not essentially constant over a considerable area.

3. Assignable causes of variation may be found and eliminated. In the development of most sampling methods, or methods of measurement, it is found that the chance cause system under which the samples are chosen or the measurements taken is not constant, because there are sometimes present certain influences or factors which can be located and eliminated.

When attempting to locate assignable causes of variation, statistical methods enable hypotheses regarding these causes to be tested and pointed out for correction.

DETECTION OF LACK OF CONTROL

The mathematics on which are based the simple arithmetical procedures for detecting lack of control cannot be described here. The methods described have been thoroughly tested and found to work, both under conditions where the basic mathematical assumptions were as nearly fulfilled as possible and in large scale manufacturing operations. Shewhart (10) describes many of these tests.

The methods developed for testing for lack of control in other laboratory measurements seem wholly applicable to a sampling study such as is here described. The use of these methods led to the detection of construction and technique defects which otherwise might have gone unnoticed in the earlier sample splitter. A number of mathematical tests were applied to the data to see if the latter conformed to the requirements of the theory; in all cases satisfactory agreement was obtained.

Two of the five tests described by Shewhart for detecting lack of control when the standard quality is unknown were used in the present studies. The first seeks to discover evidence for lack of constancy in the chance cause system; the second seeks to detect the presence of an assignable cause of variation. One test for detecting lack of control

when a standard quality is known is also presented.

TEST FOR LACK OF CONSTANCY IN THE CHANCE CAUSE SYSTEM

It has been found that, when measurements are made on a large number of samples taken from a constant chance cause system, the measurements will vary according to a mathematical law of somewhat more general form than the so-called normal law of error (10, pp. 89–94). When only a small number of samples is available, as in the present studies, the method seeks to test the hypothesis that these samples show no more variation than could reasonably be attributed to samples coming from such a distribution.

The steps involved in making this test are given in Shewhart (10). They involve (1) listing the measurements in the order in which they were made; (2) dividing the measurements into groups of four each, starting with the first (a minimum of 8 measurements or two groups of four each are required; more dependable results are obtained with more groups); (3) computing the arithmetic mean of the four values in each of the groups; (4) computing the standard deviation, σ, of the four values in each group; (5) obtaining the average of the standard deviations of the subgroups; this value is denoted by by $\bar{\sigma}$; (6) computing the average of all the X values, that is, the average of the means of the subgroups, which is denoted by $\overline{\overline{X}}$ to distinguish it from the individual subgroup averages; (7) computing the *standard error of the mean*, $\sigma_{\bar{x}}$, from the formula $\sigma_{\bar{x}} = \frac{\bar{\sigma}}{c\sqrt{N}}$ where N is the number of values in each subgroup and c is a correction factor[1] for small samples and depends on the number of measurements in the group; (8) computing the control limits of the average by the formula $\overline{\overline{X}} \pm 3\sigma_{\bar{x}}$. A subgroup average lying outside these limits is evidence of lack of control on those factors affecting the average value and is thus evidence of lack of constancy in the chance cause system. Table I shows the data required for these calculations.

TABLE I. *Summary of Calculations for Test for Lack of Control on Averages and Standard Deviations.*

Shewhart's Criterion I applied to the weight percentages on the 1.98 mm. sieve using the sample splitter shown Figure 5.

Group No.	$\overline{X}$	σ
I	18.355	1.021
II	15.262	.252
III	16.518	1.223
IV	16.865	.096
V	16.580	.796
VI	17.490	.944
Average:	$\overline{\overline{X}} = 16.845$	$\bar{\sigma} = .722$

In the above table $\overline{X}$ and σ are computed for each consecutive group of four values by procedures found in any elementary statistics textbook. The average of both the sample means and standard deviations is then computed. The standard error of the mean, $\sigma_{\bar{x}}$, and the standard error of the standard deviation, σ_σ, are computed using the formulas given in the text. The control limits on the average are given by $\overline{\overline{X}} \pm 3\sigma_{\bar{x}} = 16.85 \pm 3 \times 0.452 = 18.21$ and 15.49. The means of groups I and II lie

[1] This factor is denoted by c_2 in the discussion on page 184 of Shewhart's book and in the table on page 185; this table gives the value of c_2 for samples of size N.

TABLE II. *Statistical summary of results obtained with the coarse material using the improved sample splitter.*

Subject Unit of Measurement	Sample Weight Grams	Gravel Per Cent by Weight	Granules Per Cent by Weight	Sand Per Cent by Weight	Sample Weight Grams	Gravel Per Cent by Weight	Granules Per Cent by Weight	Sand Per Cent by Weight	Sample Weight Grams	Gravel Per Cent by Weight	Granules Per Cent by Weight	Sand Per Cent by Weight
Observed average	344.7	48.78−	35.56	15.67	348.9	49.79	36.68	13.53	347.6	49.44	36.18−	14.38
Expected average	346.8+	49.31	36.45	14.24	346.7	49.27	36.49	14.24	346.0+	49.27	36.49	14.24
Standard deviation	6.6−	1.16	.98	.41	6.7	1.24	1.07	.34−	5.3−	.83−	.70	.46
Control limits on the average	351.0 342.7	50.04 48.58	37.07 35.83	14.45 14.03	350.9 342.4	50.06 48.48	37.17 35.81	14.45 14.03	349.4 342.7	49.79 48.75	36.93 36.05	14.53 13.95
$\bar{\sigma}$, 6 groups of 4 determinations	5.25	1.04	.82	.33	4.81	1.05	.87	.30+	4.36	.72	.54	.37
Control limits on the averages*	354.6− 334.8	50.74 46.82	37.10 34.02	16.29 15.05	357.9 339.9−	51.77 47.81	38.31 35.05	14.10 12.96	355.8 339.4	50.79 48.09	37.20 35.16	15.07 13.69
Control limits on the standard deviations*	12.2 0	2.43 0	1.91 0	.77 0	11.2 0	2.46 0	2.02 0	.71 0	10.2− 0	1.67 0	1.26 0	.86 0
σ/.968 N=24	6.8	1.20	1.01	.43	7.0−	1.28	1.11	.35	5.4	.85	.72	.47
σ/.798 N= 4	6.6	1.31	1.03	.41	6.0	1.32	1.08+	.38	5.5−	.90	.70	.46
(Observed $\bar{X}$-true $\bar{X}$) $\sigma/\bar{X}$ $\sigma_{\bar{x}}$	−1.6 .019	−2.2 .024	−4.3 .028	+16.4 .026	+1.6 .019	+2.0 .025	+0.8 .029	−10.0 .025	+1.4 .015	+1.0 .017	−2.1 .019	+1.4 .032
Technique	Lugs on receiving pan were placed facing inward.				Lugs on receiving pan were placed facing outward.				Lug position on receiving pan was alternated each time the pan was changed.			
Operator	E.P.				G.O.				G.O.			

Unless otherwise stated, all results are based on samples of 24 determinations.
* These are based on samples of 4 determinations.

outside these limits, indicating lack of control.

Similarly, the control limits on the standard deviation are $\bar{\sigma} \pm 3\sigma_\sigma = .722 \pm 3 \times 0.320 = 1.682$ and -0.238. (Negative control limits are interpreted as zero.) Since no values of σ lie outside these limits, no lack of control on the standard deviations is indicated.

The control limits on the standard deviation are computed in the same manner as the steps indicated above. From these computations the standard error of the standard deviation, $\sigma_\sigma = \dfrac{\bar{\sigma}}{c\sqrt{2N}}$ is obtained when c and N are the same as before. In this case the control limits are $\bar{\sigma} \pm 3\sigma_\sigma$. If a standard deviation of a subgroup lies outside the control limits, there is evidence of lack of control on the variability of the samples and thus lack of constancy in the chance cause system is indicated.

Three times the standard error has been used for the control limits in both cases, not so much because of the theoretical probability that 99.73 per cent of the subgroup averages and standard deviations may be expected to lie inside these limits, but because these limits have been found to be economic limits. Narrower limits would occasionally indicate trouble when it did not exist. Wider limits would fail to include many cases of lack of control. With the control limits used above there is small risk that lack of control will be indicated when it does not exist.

In computing the standard errors $\bar{\sigma}/c$ is used in place of the standard deviation of the entire group of values because $\bar{\sigma}/c$ is usually the smaller when the averages are not controlled; it therefore gives a more sensitive test for lack of control. When both averages and standard deviations are controlled, and a considerable number of subgroups is used, the two measures of dispersion agree very closely. In tables II and III, note the good agreement obtained with only six subgroups except for the series in which the data are not controlled.

TABLE III. *Statistical summary of results obtained with the fine material.*

Subject Unit of Measurement	Improved Sample Splitter				Sample Splitter Shown in Figure 5			
	Sample Weight Grams	Granules Per Cent by Weight	Coarse Sand Per Cent by Weight	Fine Sand Per Cent by Weight	Sample Weight Grams	Granules Per Cent by Weight	Coarse Sand Per Cent by Weight	Fine Sand Per Cent by Weight
Observed average	134.5	16.96	47.29	35.75*	138.2	16.85−	46.78	36.37
Expected average	134.9	17.38	47.61	35.01	134.9	17.41	47.59	35.00
Standard deviation	1.7	.90+	.83	.78	9.8	1.26	1.27	2.12
Control limits on the average	136.0 133.8+	17.95 16.81	48.14 47.08	35.50 34.52	141.0+ 128.7	18.21 16.61	48.39 46.79	36.34 33.66
$\bar{\sigma}$, 6 groups of 4 determinations	1.4	.72−	.70	.56	8.2+	.72	.73	.91+
Control limits on averages†	137.1+ 131.9	18.30 15.62	48.60 45.98	36.80 34.70	153.7 122.7	18.21 15.49	48.15 45.41	38.09 34.65
Control limits on standard deviations†	3.2+ 0	1.67 0	1.63 0	1.30 0	19.2 0	1.68 0	1.70+ 0	2.13 0
$\sigma/.968$, $N=24$	1.8	.93	.86	.80	10.1	1.30	1.31	2.19
$\bar{\sigma}/.798$, $N=4$	1.7+	.90−	.88−	.70	10.3+	.90+	.92	1.14+
Observed $\bar{X}$-true $\bar{X})/\sigma_{\bar{x}}$	−1.1	−2.2	−1.8	+4.5*	+1.6	−2.1	−3.0	+3.1
$\sigma/\bar{X}$	.013	.053+	.018−	.022	.071	.075	.027	.058
Technique	Lugs on receiving pan were placed facing outward.				Scoop was used for pouring as described in text.			
Operator	E.P.				Runs 1–20: L.Z. Runs 21–24: E.P.			

* This bias could be eliminated by alternating the receiving pan position each time the pan is interchanged.
Unless otherwise stated, all results are based on samples of twenty-four determinations.
† These are based on samples of 4 determinations.

TEST FOR LACK OF CONTROL IN RESPECT TO STANDARD QUALITY

For each of the two mixtures studied, the average sample weight which should be obtained is known; also, the actual percentages retained on each of the two sieves are accurately known. These values, then, furnish a *standard of quality* by which the performance of the sample splitter may be measured. If the average of a series of N determinations differs from the true or expected value by an amount which is greater than could reasonably be attributed to random sampling fluctuations, the fact is taken as evidence of lack of control.

A different *standard error of the mean* is employed. This time, only one group of 24 measurements is available for its estimation. (In the previous test, six groups of four determinations each were available.) The standard error of the mean is the standard deviation of a frequency distribution of averages of samples of size N. Suppose that a large number of groups of 24 measurements each is obtained and the average value is determined for each group. The standard deviation of these averages is the standard error of the mean. Ordinarily it is estimated from the value of a single group. This estimate occasionally may be quite far from the true value, but the chances are large that it is close enough to be serviceable. An estimate based on a sample of 25 or more measurements possessing a low ratio of standard deviation to average value is reliable for most work.

The first two series using the coarse mixture were run in such a way that the standard deviations should remain essentially unchanged. The changes in technique should affect mainly the direction of sign in the bias. Note the stability in the corresponding standard errors for coarse material.

	Sample wt.	*Pea Gravel*	*Granules*	*Sand*
Lugs facing inward	1.38 g.	0.244%	0.207%	0.089%
Lugs facing outward	1.42 g.	.262%	.226%	.071%

Several factors cause the bias, but in the present case the most important seems to be the following. Refer to the upper drawing on figure 2; note that only the receiving pan is shown and that an abnormal fraction enters the receiving pan at the left side and the reject pan at the right side. Because of frictional drag on the sides, the smaller grains tend to get into these abnormal fractions. It follows that the coarser particles which *were* along the the sides tend to get moved over to the next chute. Because the same process happens at both ends of the pouring pan, the contents of the reject and receiving pans have the same average composition after the first passage. If the receiving pan contents are now emptied into the hopper without changing the orientation, the right hand side, which has just been shown to contain too much coarse material is now lost to the reject pan. The average composition in the receiving pan is now too high in fines and will continue to become more biased as the subdivision is continued.

If the receiving pan lugs are facing outward at the start, the pan will have to be turned each time, and the fine end will be lost to the reject pan.

When the lug positions are alternated, a compromise is effected. The two errors of opposite sign nearly compensate each other. Brunton (3) seems to have had this explanation in mind when discussing the bias usually present in a series of Jones sample splitters arranged in tandem.

When the quantity of coarse material is small as in the fine mixture, the error just described is much less important. In such a case, it seems that accidental variations in width of chutes and the shape of the hopper end plates are the major sources of error. Here again, reversing the pan positions will tend to compensate these errors.

The actual computation of the control limits is done essentially as in the other test. The true mean is used in place of the observed value; the standard deviation of the entire set of measurements is used. The value of the correction factor for small samples is changed to suit the larger size of N.

If the observed average value lies outside these limits, there is evidence for lack of control; such a condition indicates bias in the sample splitter and may result from defective design or construction or from defective technique of operation.

When it is desired to compare the bias in a series of values it is preferable to determine the ratio of the difference between the observed and expected averages to the standard error of the mean. The calculations are shown below, assuming that the average and standard deviation of the group have been calculated.

$0.336\% = \sigma$ (standard deviation of the 24 values).

14.24% = true percentage of material passing the .991 mm. sieve.

13.53% = observed mean.

0.968 = correction factor for sample size of 24.

$$\sigma_{\bar{X}} = \frac{.336}{.968\ \sqrt{24}} = (.211)\ (.336) = .071$$

$$\frac{\text{observed mean-true mean}}{\sigma_{\bar{X}}} = \frac{13.53-14.24}{.071} = \frac{-.71}{.071} = -10$$

Since the ratio is far outside the range ± 3, bias is indicated beyond question. Tables II and III show the ratio (observed mean-true mean)/$\sigma_{\bar{X}}$, for the determinations on both the coarse and fine material.

TEST FOR THE PRESENCE OF AN ASSIGNABLE CAUSE OF VARIATION

Two methods for detecting an assignable cause of variation were used. In the first, some change was made in a detail of design or operation and a new series of measurements was made. The tests previously described were applied to the data to see if the bias had been removed and if the data were otherwise controlled. The standard deviations were also compared. More refined methods of study gave little additional information of practical use. This first method requires that a possible cause of variation be known.

The second method may be applied without such knowledge whenever two or more measurements have been made on each of a series of samples. If the data have previously shown lack of constancy in the chance cause system, the test cannot be interpreted literally, since it involves the correlation coefficient,[1] use of which is valid only when the data are known to have some from an approximately

[1] The reader is referred to any standard textbook of statistics for a full discussion of the correlation coefficient.

normal distribution. However, when the data come from a constant chance cause system, it is quite probable that they also come from such a distribution. A further check was made on the validity of using the correlation coefficient in the present study: the individual measurements on weights and percentages from which table IV was calculated were ranked according to size. From the standard deviation of the group and the observed average, the limiting values were calculated corresponding to the probable error and one, two and three standard deviations. When the data were controlled, the number of values falling inside these limits was in all cases close to the theoretical number.

The usual simple formulas for interpreting the correlation coefficient were not intended for as few as 24 pairs of observations. Fisher (5) developed a transformation for such cases, in which a new value z was found in terms of the correlation coefficient r. The value of z may be obtained from a short table of hyperbolic tangents such as that by Peirce (8). If, as Shewhart (10) has shown, the value of z lies outside the limits $\pm\frac{3}{\sqrt{N-3}}$, the presence of a cause of variation simultaneously affecting both variables is indicated.

TABLE IV. *Transformed correlation coefficients.*
$z = \tanh^{-1}(r)$

COARSE MATERIAL

Method	Variables Correlated	Gravel	Granules	Sand
Lugs on receiving pan were placed facing inward.	Sample weight	+1.11*	− .90	− .62
	Gravel		−1.72	− .64
	Granules			+ .25
Lugs on receiving pan were placed facing outward.	Sample weight	+ .66	− .56	− .56
	Gravel		−2.06	− .70
	Granules			+ .40
Lug position on receiving pan was alternated each time the pan was changed.	Sample weight	+ .45	− .38	− .22
	Gravel		−1.20	− .60
	Granules			− .02

FINE MATERIAL

Method	Variables Correlated	Granules	Coarse Sand	Fine Sand
Lugs on receiving pan were placed facing outward.	Sample weight	+ .48	+ .01	− .60
	Granules		− .70	− .57
	Coarse sand			− .39
Sample splitter shown in fig. 5 was used as described in text.	Sample weight	+ .04†	+ .14	− .11
	Granules		+ .43	−1.21
	Coarse sand			−1.22

* Values of z outside the limits ± 0.65 are probably significant.
† These correlation coefficients have only a qualitative significance.

The method does not tell what the cause is; it does tell something important about the cause. Before the test was applied it was not possible to state whether such a cause group even existed. Table IV gives the transformed correlation coefficients.

STATISTICAL BASIS FOR IMPROVEMENTS IN DESIGN

An earlier design of the improved sample splitter sought to eliminate the personal element in the operation and to increase the allowable size of material which could be sampled. The statistical analysis of the data from the earlier form showed beyond reasonable doubt that there were causes of variation which could be eliminated if only they could be found. This was the most important result obtained. The experiments on hopper design were conducted using only sample weights to indicate the presence of trouble. The first two tests for lack of control were applied. The changes in the standard deviation were noted for each modification of the technique or design. These studies indicated that better results would be obtained with a low hopper.

It was decided at the outset of the tests on the final improved sample splitter that the percentages actually present ought to be known, since ordinary observations on the other instrument showed a preferential loss of certain sizes of particles to one side of the splitter. The present mixtures were planned to make it especially difficult to obtain accurate samples by introducing two discontinuities in the size frequency distribution and making the mixture trimodal.

The tests on the final splitter were begun on the coarse mixture with the lugs of the receiving pan facing inward just as a matter of convenience. Statistical analysis of these data showed a large bias in the average percentage in the pan. It was also found that the percentages on the coarse sieve were correlated with those on the sieve just beneath despite the absence of sieving errors. The sample weights were also correlated with the amount of the two coarser sizes present. The high correlation coefficients were interpreted to mean that some factor affected only the amount of coarse material.

A new series was then run with the receiving pan lugs facing outward. The bias was still present, but reversed in sign. The fact that many other statistics changed little confirmed the opinion that determinations on 24 samples were sufficient to give stable values, despite the fact that this second series was done by a different operator.

In addition to the statistical study previously made, a similar study was carried out for three weight ratios: weight of pea gravel to weight of granules, weight of granules to sand, and weight of pea gravel to sand. An analogous but less pronounced bias was still present. The ratios showed no indication of lack of constancy in the chance cause system from which they were derived. The correlation coefficients were generally lower. Insofar as could be ascertained, a study of the ratios seemed to afford a less sensitive indication of trouble than a study of the actual percentages and was therefore discontinued. Furthermore, it was difficult to get a physical picture for many of the correlation coefficients.

A comparison of the first two groups of correlation coefficients given in table IV shows that the first group, in which the receiving pan lugs were facing inward, consistently has larger values for the coefficients involving the sample weight, and smaller values for the coefficients between the percentages themselves. These differences, unlike those of the bias, seem to result mainly from differences in the rate of pouring; the lug position is probably a factor of secondary importance operating in the same direction. The samples for the second group were obtained with a faster pouring rate than was used for the first group. Studies made on the earlier form of sample splitter indicate that in general high pouring rates tend to decrease bias caused by the technique or construction of the instrument, to increase the standard deviations of the sample weights and percentages and to decrease correlations of percentages with sample weights. These principles are found to apply here, but it must be emphasized that the important reversals of the *sign* of the bias are solely the result of the receiving pan orientation.

In obtaining the samples of the third se-

ries, in which the pan lug positions were alternated, a moderately fast pouring rate was used. In accordance with expectations the bias was completely eliminated, all the correlation coefficients showed a decrease and only one significant value remained; this was noticeably lower than before. Three of the four ranges and three of the four standard deviations were reduced by substantial amounts. All the evidence showed that a state of control was being approached. Further investigation was considered unnecessary.

It has been observed in manufacturing studies that, as a state of control is approached, the variability in the product diminishes; it has also been noticed, that, after thorough statistical tests have shown no evidence of lack of control, further reduction in the variability of the product will be effected only by basic changes in design or operation.

The application of the latter principle to the one remaining evidence for lack of control leads to the conclusion that there is still room for some improvement without changing the basic design. A number of other tests for detecting lack of control were not applied, largely because of the paucity of measurements. These might indicate additional assignable causes of variation.

In order to afford the interested reader a detailed demonstration of the results obtained with the improved sample splitter, table V is given here. It includes data on the 24 sieve tests made with the coarse mixture and indicates that the theoretical values and observed results agree quite closely.

TABLE V. *Results obtained with improved sample splitter.*

Run No.	Sample Weight in Grams	Per Cent *by Weight* on 3.33 mm. Sieve	Per Cent *by Weight* on .991 mm. Sieve	Per Cent by Weight in Pan
1	350.1	49.17	36.97	13.85
2	346.6	48.32	37.31	14.37
3	346.9	49.76	36.24	14.00
4	346.7	50.33	36.23	13.44
5	338.5	49.11	36.36	14.53
6	344.9	50.92	35.37	13.71
7	353.5	48.57	36.64	14.79
8	356.8	49.79	36.08	14.13
9	346.4	49.12	35.81	15.07
10	348.9	49.76	35.59	14.65
11	339.8	49.52	36.25	14.23
12	350.0	50.12	35.62	14.26
13	349.9	50.23	34.53	15.24
14	350.2	49.40	36.10	14.50
15	338.4	48.29	36.58	15.13
16	354.1	49.38	36.37	14.25
17	353.2	50.11	35.52	14.37
18	352.1	49.70	35.50	14.80
19	346.3	49.19	36.47	14.34
20	353.8	50.50	35.86	13.63
21	341.1	49.39	36.24	14.37
22	338.3	46.91	38.15	14.94
23	350.8	49.20	36.49	14.31
24	345.1	49.87	35.96	14.17
Component		Pea gravel	Granules	Sand
Average	347.6	49.44	36.18	14.38
Expected average	346.0	49.27	36.49	14.24
Difference	+1.6	+.18	−.31	+.14
Method	Lug position on receiving pan was alternated each time the pan was changed.			

SUMMARY

An improved sample splitter for laboratory use has been described. It was compared with a good commercially obtainable instrument and found to be superior in the following ways:

1. It is faster to operate, will handle coarser material, and has a larger capacity; there is no sacrifice of dependability when the samples are small.

2. The samples obtained with this improved splitter are free from occasional erratic samples.

3. A large reduction in the variability of the samples was obtained with the improved splitter, even when an inferior technique was used.

4. Different operators, without previous experience, can obtain comparable results.

5. No special skill or training is necessary for even the most efficient mode of operation.

The concept of a state of control and the concept of a constant chance cause system were discussed in their relation to geological sampling problems.

Methods for detecting lack of control in a series of samples were explained in terms of (1) the detection of a lack of constancy in the chance cause system under which the samples were taken; (2) detection of a significant variation of the average of a series of measurements from some standard value or quality; (3) detection of an assignable cause of variability.

The application of these methods led to final improvements in design and technique by pointing out the unsuspected existence of a lack of control and occasional erratic results in the earlier form of the splitter.

The writer wishes to acknowledge assistance from Dr. R. T. Knapp who contributed a detail of the design, and Messrs. H. Kurihari, D. Luckenbill, E. Porter and L. Zuckerman who did much of the laboratory work and routine calculations. J. Hough made suggestions regarding the tests on the commercial sample splitter, and E. Porter made suggestions regarding technique for the improved splitter. Professors I. Campbell, W. Houston and H. Gilbert of the California Institute of Technology read and criticized the manuscript.

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A CORRECTION BY H. C. STETSON

Correction for article on the "Bottom Deposits of the Ross Sea" by Stetson and Upson

In the August 1937 number of this JOURNAL a correction should be made in the article on the "Bottom Deposits of the Ross Sea" by H. C. Stetson and J. E. Upson. Page 57, second column, lines 27 and 28 should read 160 E. Long. instead of W. Long. and 90 W. Long. instead of E. Long. The caption for Fig. 1, page 56, should read "Positions of bottom cores."

REVIEWS

MAGNÉE, I. DE, et MACAR, P., *Données nouvelles sur les sables des Hautes Fagnes*, Annal. de la Soc. Géol. de Belgique, T. LIX, B 263–288, 1936.

This paper, which treats of the heavy minerals, mechanical composition, stratigraphy, and distribution of the sands named, is based in part on two earlier papers by Macar (Analyses granulométriques de sables tertiaires des environs de Liége, *ibid.*, 1934; Quelques analyses granulométriques de sables d'origine marine et éolienne de la côte belge, *ibid.*, 1935). In these papers Macar stressed the following methods in correlating by mechanical analysis: (a) use of Tyler sieves for analysis, using eight sieves for the sizes between 0.833 and 0.074 mm; (b) statement of results as tables of weight percentages, together with Wentworth's three statistics: mean size, standard deviation, and skewness; (c) the importance of the mean grain size, in particular, and also of the relation of the most frequent size to the others, and the positive or negative value of skewness; and (d) the necessity of examining a sufficient number of known samples before trying to correlate unknown samples with them.

In the paper under review, the methods of heavy mineral study do not differ from those commonly used: separation of fifty-gram samples in bromoform; mounting in Canada balsam; counting from 300 to 700 grains—the procedure being essentially that of Edelman. The application of these methods, however, has special interest in Belgium.

The marine Cretaceous and older rocks (especially Cambrian quartzites) contain a small suite of very stable minerals—zircon, tourmaline, rutile, and opaque oxides. This is, of course, true also of the sands which take origin locally from these beds. On the other hand, the marine Tertiary sands contain a number of additional species—staurolite, zoisite, kyanite, topaz, and andalusite. In the absence of fossils, these heavy minerals make it possible to differentiate the Tertiary rocks from the older ones, as well as from the younger, local sands. It is true that some beds show a mixing of the two suites, as can be told both from a gradual change from one pure type to the other, or from the fact that the very stable species, which are present in both suites, are larger in every case in the Tertiary rocks. Their presence in two sizes is presumptive evidence of mixing.

The mechanical composition bears out this thesis in a most interesting way. When mixing is indicated by the heavy minerals, the histograms have two definite maxima—showing the advent of material from two different sources, brought in by different agencies. In addition, the value of skewness was used, though in a tentative way, to show the difference between the marine sediments and those formed locally under non-marine conditions.

The use of these methods led the authors to important paleogeographical results, serving to delimit the invasion of the Tertiary seas. In a case of this sort, one has to deal in part with negative evidence, since the absence of the Tertiary minerals might indicate no more than subsequent erosion. However, the authors have given supplementary information, not pertinent here, which bears out the conclusions drawn from their study of the sediments.

LINCOLN DRYDEN

Bryn Mawr College
Bryn Mawr, Pa.

RUSSELL, R. J., *Physiography of Lower Mississippi Delta.* Louisiana Geol. Survey, Geol. Bull. 8, pp. 3–199, 1936.

This article considers the topography of the delta by districts; the land forms of the delta; the hydrography; sedimentation over the delta; thickness of sediments beneath the delta; age of the delta; load upon the basement rocks; the evidence, rate, and causes of submergence; and the Gulf Coast Geosyncline.

The author's method of presentation of each subject is to go back to original sources for definitions, to give opinions of numerous students on each subject and to follow with his own. The author seems to be seriously concerned in adherence to the original definition of a delta given by Herodotus and subse-

quently given by Dana that a delta is a region and not a sedimentary deposit, and he seems to object to the now rather general usage of the term with the meaning of an alluvial deposit at the mouth of a stream. He is also much concerned in demonstrating that accumulation of the materials of a delta produce downwarping of the crust and he takes to task those who disagree with this view. His characterization of the studies of Barrell as an "armchair survey" is an example of this impatience which might well have been omitted (p. 184). His criticism of Schuchert in his statement of "reluctance to accept observation because it fails to support a theoretical concept" might have been stated in more courteous terms. Much concern is felt over the existence of the Gulf Coast Geosyncline which some students have not been inclined to accept, and the author thinks this syncline was caused by deposition. The concept of topset, foreset, and bottomset beds of deltas is depreciated in the statement that the Mississippi River Delta does not support such an arrangement. The reviewer does not know of any sedimentationist who maintains that the concept as theoretically expressed is anywhere shown to perfection in a delta any more than one may see the strain ellipsoid so commonly used by structural geologists.

Much detailed information is given respecting the various subjects considered. All of this is of interest but much does not relate to sediments and sedimentation. The author agrees with Shaw and Hilgard that mud lumps are due to loading and thinks that the clay of the lumps probably originated on the outer sides of bars "as suggested by texture and fineness of grain which resemble deposits developed through flocculation." Data are given on the rate of deposition of sediments and the thickness of alluvium of the delta. He states as his opinion that the Mississippi River carries an average of at least 2,000,000 tons of sediment to the Lower Delta each day.

The paper presents an abundance of data derived from personal field studies of the Delta and is extremely valuable on that account. The presentation is very readable, but the author's interpretations seem to the reviewer to have a tone of finality that mars the work. Interpretations are but interpretations and like those made by earlier men these are apt to be not entirely correct.

W. H. TWENHOFEL
University of Wisconsin

DOHM, C. F., *Petrography of Two Mississippi River Subdeltas*, Louisiana Geol. Survey, Geol. Bull. 8, pp. 339–402, 1936.

The two subdeltas from which the sediments described in this paper were derived are in the Plaquemines and St. Bernard parishes. Plaquemines Parish includes the region lying on both sides of the Mississippi River south of New Orleans to the mouths of the river and St. Bernard, that part of the delta southeast of New Orleans between Lake Borgne and Mississippi Sound and the Gulf of Mexico. The samples were obtained from 131 stations. Each sample is described in tabulate form.

The literature relating to the sediments of the two parishes is reviewed and the methods of mechanical analysis employed are described. The hydrometer method was employed with corrections for density readings, after which evaluation of grain size was made from a chart. The results were then placed in graphic form. There are 100 graphs.

The analyses for minerals attempted to follow the method outlined by Rubey (This JOURNAL, 3 (1933), pp. 3–30). Bromoform was used to separate the heavy from the light suite of minerals. The results are given in tables.

The general results of the study indicate that dune sands show the best sorting, followed in order by beach sands, channel deposits, marsh deposits, and materials of the mud lumps. Neither an increase nor a decrease of transporting ability is shown by comparison of the sediments of the two parishes.

W. H. TWENHOFEL
University of Wisconsin

BRAGG, W. L., *Atomic Structure of Minerals*, Cornell University Press, pp. 1–292, 1937.

This book is the first complete consideration of the atomic structure of minerals and brings together in one place more or less

widely scattered information. It consists of two parts of which the first treats of "Crystal Structure and X-ray Analysis" in three chapters as follows: "Geometry of Crystal Pattern," "Analysis of Crystals by X-rays" and "General Principles of Mineral Structures." The second part gives "Descriptions of Mineral Structures" in thirteen chapters, each chapter considering a group of minerals as follows: elements, halides; sulphides, arsenides, and related compounds; oxides; oxygen-salts; structure of silicates; silicates containing separate SiO_4 groups; alumino-silicates; structures containing complex silicon-oxygen groups; pyroxene and amphibole groups; mica and clay groups; apophyllite; feldspar group; zeolites and other framework structures. An appendix gives the nomenclature of the space-group.

The layman should not have much difficulty in reading and understanding this book. Although technical it is extremely readable. There are 144 well selected illustrations that greatly aid in understanding the descriptions and permit the reader to see how the atoms are actually arranged in crystals. The book is a valuable addition to the library of geologists, mineralogists, chemists and physicists.

W. H. TWENHOFEL
University of Wisconsin

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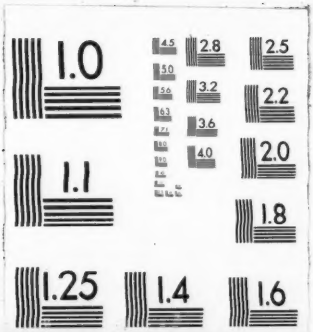
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